



# COMPUTER SIMULATION OF AN AIRCRAFT ENGINE FUEL INJECTION SYSTEM

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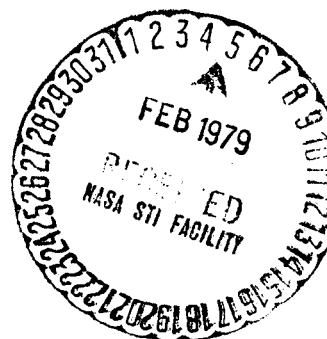
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## FINAL REPORT



SEPTEMBER 1978



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16. Abstract  The purpose of phase III of the contract was to develop an analytical model of the Teledyne Continental fuel system to provide a basis for quantitatively exploring deficiencies in the system response which lead to poor exhaust emission characteristics. A computer model of the fuel system was developed based on component testing and found to give accurate predictions for pressures and flow rates within the system. The model has been used to investigate modifications to the system for improved fuel management and reduced exhaust emissions. The effect of improved fuel management on engine exhaust emissions was evaluated.					
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# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons	0.9	tonnes	t
	(2000 lb)			
<b>VOLUME</b>				
tsp	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>

## TEMPERATURE (exact)

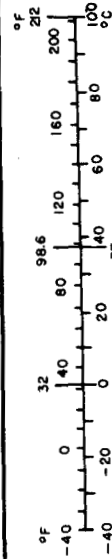
Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C
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## Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	
<b>MASS (weight)</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>

## TEMPERATURE (exact)

Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F
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\* 1 in. = 2.54 (exact). For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, Units of Weights and Measures, Price \$2.25, SD Catalog No. C13.10-286.

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# LIST OF SYMBOLS

<u>Symbol</u>	<u>Meaning</u>	<u>Units</u>
A	Area	Square Inch
$A_e$	Relief Valve Diaphragm Effective Area	Square Inch
$A_v$	Valve Area	Square Inch
CHT	Cylinder Head Temperature	Degrees Fahrenheit
$C_d$	Orifice Discharge Coefficient	-
D	Line Diameter	Inch
DISP	Pump Displacement	Cubic Inch
EGT	Exhaust Gas Temperature	Degrees Fahrenheit
F	Objective Function	-
F1-F11	Remainder Terms from Flow Equations	-
F ( $\Delta P$ )	Pump Leakage function	Pounds per Hour
F/A	Fuel to Air Mass Ratio	-
$K_f$	Line Loss Factor	-
$K_o$	Line Loss Factor for Bends, Valves and Fittings	-
$K_s$	Spring Constant	Pounds per Inch
L	Line Length	Inch
N	Pump Speed	Revolutions per Minute
PAMB	Ambient Pressure	Pounds per Square Inch Absolute
P1	Pump Inlet Pressure	Pounds per Square Inch Absolute
P2	Pump Discharge Pressure	Pounds per Square Inch Absolute



List of Symbols - cont'd

<u>Symbols</u>	<u>Meaning</u>	<u>Units</u>
P3	Ambient Pressure	Pounds per Square Inch Absolute
P4	Nozzle Inlet Pressure	Pounds per Square Inch Absolute
P5	Turbo Discharge Pressure	Pounds per Square Inch Absolute
P6	Variable Orifice Discharge Pressure	Pounds per Square Inch
P7	Vapor Return Line Pressure	Pounds per Square Inch
Pds	Downstream Pressure	
Q	Fluid Dynamic Head	
Re	Reynolds Number	-
R <sub>r</sub>	Orifice Rod Radius	Inch
R <sub>o</sub>	Variable Orifice Radius	Inch
RF	Fuel Pressure Force on Variable Orifice Rod	
RPM	Pump or Engine Rotational Speed	Revolutions per Minute
T	Temperature	Degrees Fa
W	Mass Flow Rate	Pounds per Hour
Z0	Supply Line Elevation at Tank	Inch
Z1	Supply Line Elevation at Pump	Inch
ALS	Relief Valve Spring Compression	Inch
ΔP	Pressure Differential	Pounds per Square Inch
ΔP <sub>v</sub>	Valve Pressure Differential	Pounds per Square Inch

List of Symbols - cont'd

<u>Symbols</u>	<u>Meaning</u>	<u>Units</u>
$\Delta P_t$	Throttle Pressure Drop	Pounds per Square Inch
$\delta$	Variable Orifice Displacement from Closed Position	Inch
$\delta_{ADJ}$	Variable Orifice Adjustment	Inch
$\epsilon$	Surface Roughness	Inch
$\eta$	Pump Efficiency	-
$\mu$	Fluid Viscosity	Pounds Mass per Foot Per Second
$\rho$	Fluid Density	Pounds Mass per Cubic Foot

## INTRODUCTION

### Purpose

The purpose of this report is to develop a computer simulation of the TCM fuel injection system to serve as a tool for the evaluation of schemes for improved fuel management. Using the simulation, the effects of fuel system modifications on fuel flow rate are evaluated at various engine operating and environmental conditions. The impact of modifications on emissions and fuel economy are determined.

### Background

This report describes work performed under the first option of Phase III of National Aviation Facilities Experimental Center (NAFEC) contract DOT FA74NA-1091 by Teledyne Continental Motors (TCM). Prior testing of TCM engines under Phase I of this contract has shown that a significant reduction in emissions is available through improved fuel management. Phase II of the contract entitled "Corrective Measures Determination" involves an investigation of concepts which offer the most promise toward achieving the emissions levels required by proposed Environmental Protection Agency (EPA) standards. However, analysis accomplished under a National Aeronautics and Space Administration (NASA) contract (NASA contract NAS3-19755) fulfilled the purpose of Phase II, eliminating the need for duplicating this effort under NAFEC contract (reference 1). Phase III of the NAFEC contract DOT FA74NA-1091 was concerned with the analysis, design, construction and testing of fuel injection system based on the system currently manufactured at Continental.

Phase III was divided into three options. The objectives of the first option were:

- (1) Define the fuel system requirements.
- (2) Develop a generalized analytical model of the TCM fuel injection system.
- (3) Measure the response of the TCM fuel injection system to varied operational conditions.
- (4) Refine the analytical model to correlate with system measurements.
- (5) Use the model to predict component requirements for fuel/air ratio control.

This report describes the work performed under the first option of Phase III. The second and third options were concerned with the modification of the current system and subsequent testing. These options were cancelled due to a proposed elimination of the emissions standards for aircraft piston engines.

### Overview

To understand the Continental fuel injection system and its effects on aircraft engine emissions, it is necessary to understand the operating limitations of the air-cooled aircraft internal combustion engine. These limitations are primarily imposed by cooling requirements, detonation limits, and acceleration characteristics of the engine. The Continental fuel injection system was designed to avoid over-heating and detonation by supplying excess fuel at high power. A typical fuel flow schedule is shown in figure 1, which shows an increase in the slope of the fuel flow schedule above 75 percent power to provide additional fuel for cooling. At cruise power (75 percent) and below, the primary consideration is engine acceleration, although cooling can be a problem during aircraft ground operations (taxi).

In order to obtain better cruise economy for steady state operation, the Continental system is equipped with a manual mixture control. This control is a fuel pump bypass which is used at the option of the pilot at 75 percent power and below to reduce fuel flow. Figure 2 shows the benefits of leaning. Although power drops with increasingly lean fuel/air ratios, specific fuel consumption drops approximately 15 percent from best power fuel/air to best economy fuel/air. Below 75 percent power, manual leaning is limited by instructing the pilot to lean no more than 50° Fahrenheit (F) rich of peak exhaust gas temperature (EGT). Figure 1 shows the region of the fuel schedule where manual leaning is permitted.

The effect of leaning on engine emissions was investigated during phase I of (NAFEC) contract DOT FA74N1091 (reference 2) where it was found that leaning generally reduces hydrocarbons (HC) and carbon monoxide (CO) while increasing nitrogen oxides (NO). For the baseline engines, HC and CO emissions exceed (EPA) standards. However, NO emissions are considerably below the standards. Therefore, leaning is a means of reducing the emissions which exceed the EPA standards. Improvement must be

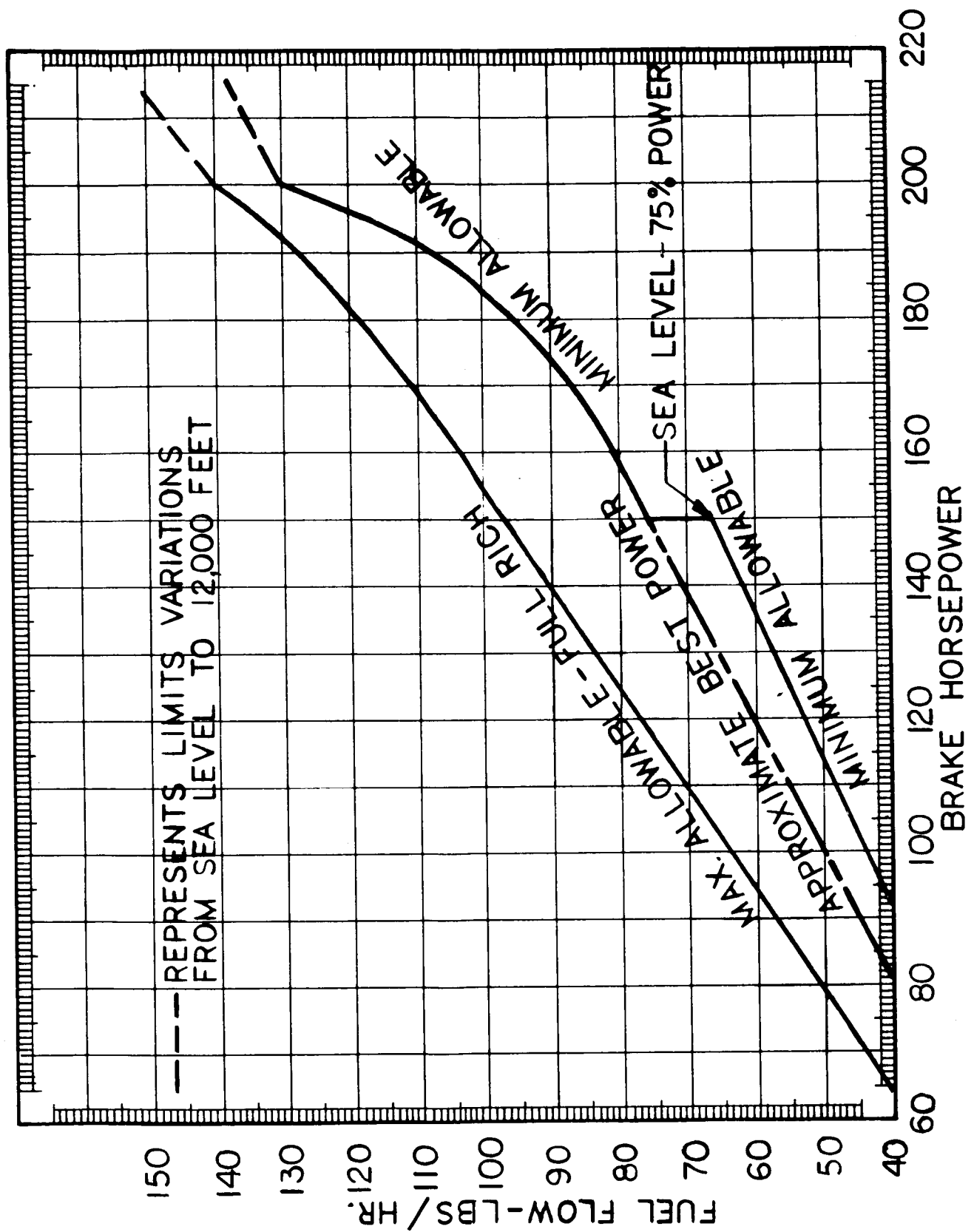


FIGURE 1. FUEL FLOW LIMITS FOR TSIO-360-E ENGINE

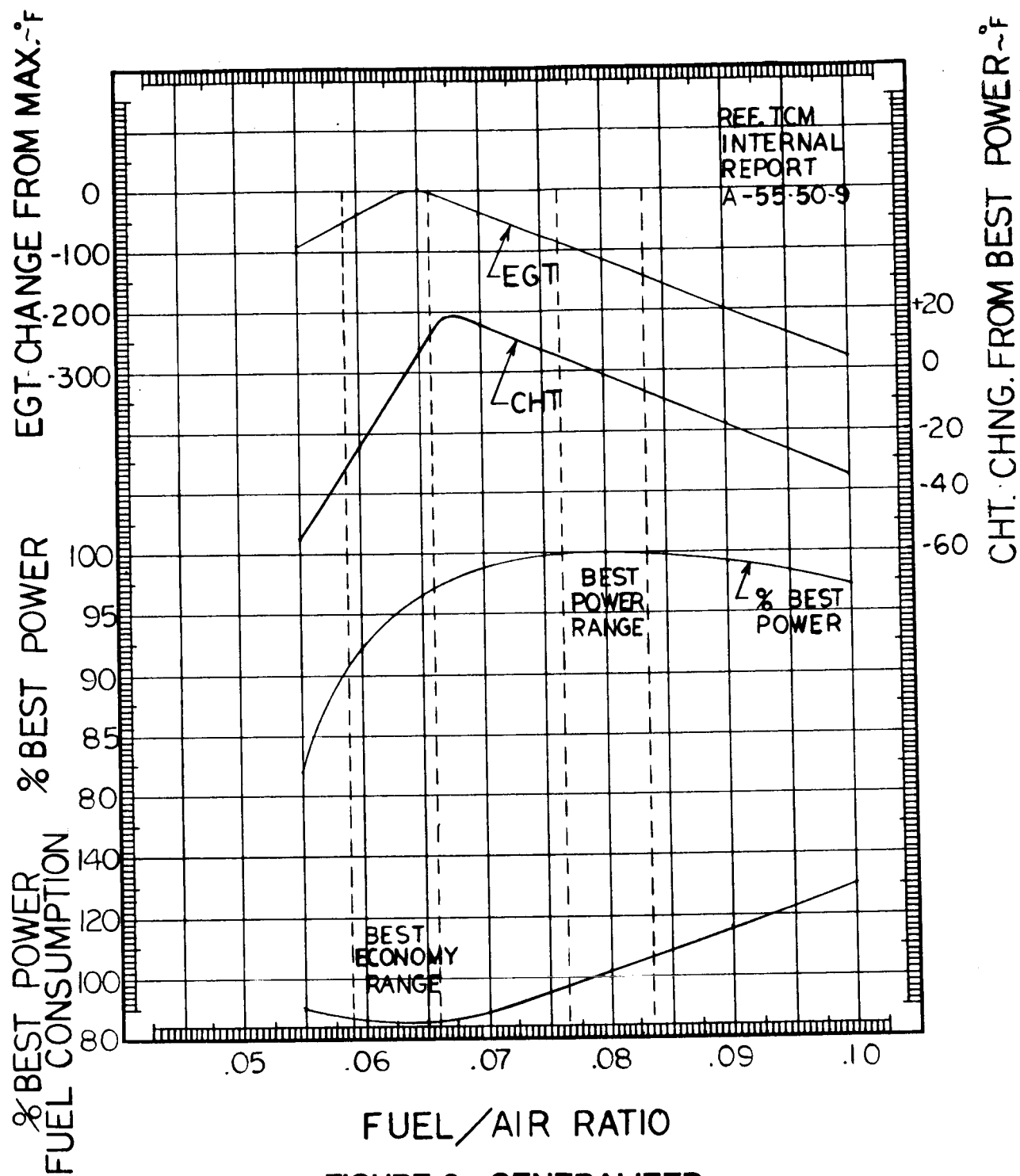


FIGURE 2. GENERALIZED  
MIXTURE RATIO CURVE

made to the current fuel injection system and perhaps the air intake manifold to safely lean for reduced emissions during the landing and takeoff (LTO) cycle, where the engines are operated full rich.

Improvements to the fuel system in the form of additional or modified hardware cannot be made without an understanding of the fluid behavior within the system. Phase III, Option I, of the NAFEC Contract DOT-FA74NA1091 was awarded to Teledyne Continental Motors (TCM) to investigate the current fuel injection system and develop an analytical simulation. This simulation is to serve as the basis for quantitatively exploring deficiencies in the fuel system which lead to poor exhaust emissions characteristics. The simulation was based on component behavior as determined from component bench tests. The model was written in modular format to readily allow simulation of fuel system hardware changes for improved fuel management.

## DISCUSSION

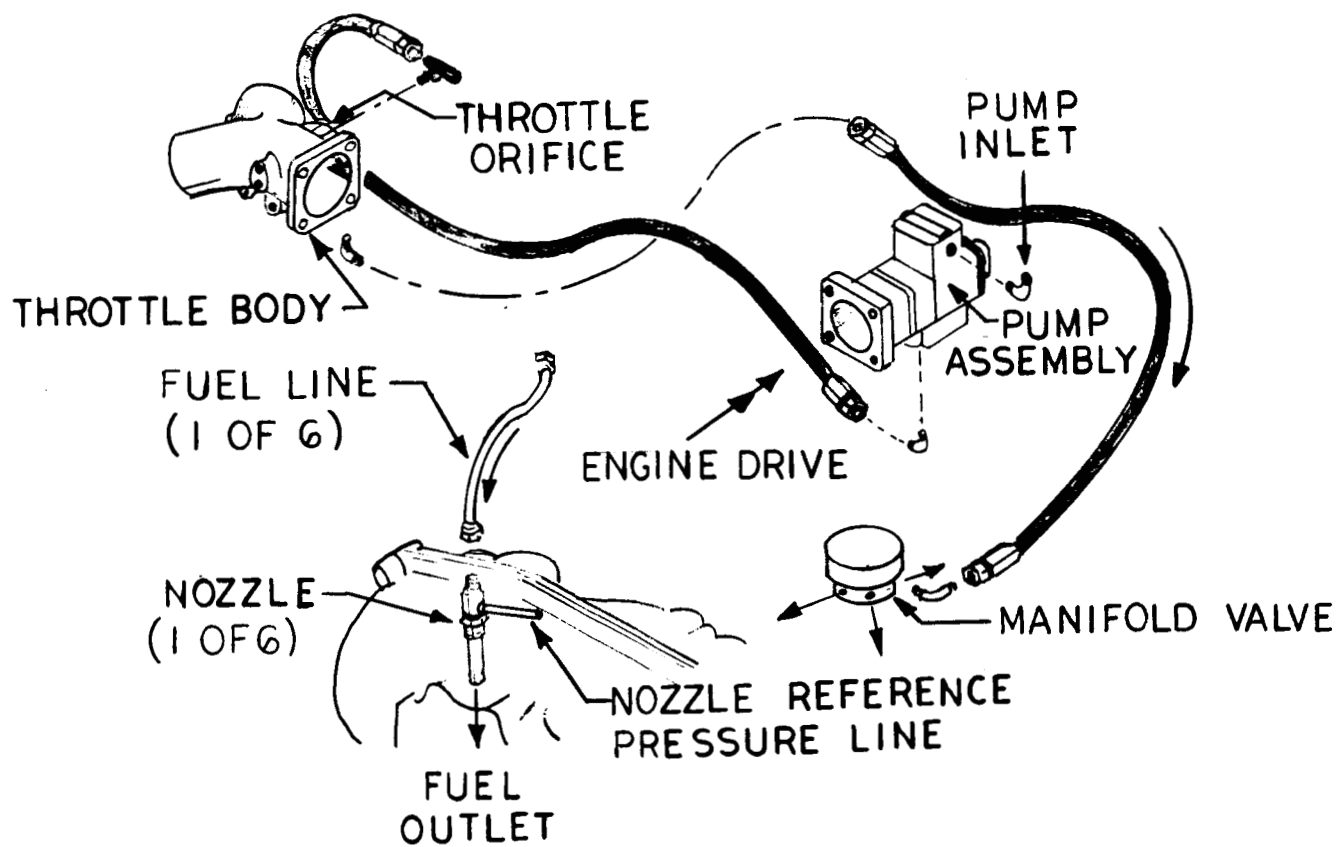
### Description of the Continental Fuel Injection System

The fuel injection system chosen for simulation is designed for the TSIO-360-E and LTSIO-360-E engines. These engines currently lead Continental's line of turbocharged engines for rate of production. The LTSIO-360-E and TSIO-360-E are counter-rotating 200 horsepower engines produced for the rapidly expanding twin engine aircraft market. The fuel system used on these engines was developed by modifying previous Continental designs and shares many common components with other Continental fuel systems. The components of the system are shown in figure 3. Injector nozzles spray fuel continuously into the intake port of each cylinder where the fuel is further vaporized by cylinder air intake. The fuel/air mixture enters the combustion chamber when the intake valve opens. The amount of fuel delivered is determined by engine speed, turbocharger discharge pressure, throttle angle, and ground trim adjustments.

A schematic of the fuel injection system used on Continental turbocharged engines is shown in figure 4. The heart of the system is a rotary vane pump which is driven at a 1:1 ratio by the engine and delivers flow in direct proportion to engine speed. The pump is bypassed by the variable orifice and idle relief valve which to a large extent govern the output pressure of the pump. As more flow is bypassed at a constant pump speed, pump pressure drops. The idle relief valve is effective at low pump speeds and is ground adjusted to set the minimum pump discharge pressure at idle. The variable orifice is ground-adjusted to trim pump pressure at full power. The action of the aneroid adjusts the variable orifice rod to increase pump discharge pressure with increasing turbocharger discharge pressure. This aneroid action tends to increase fuel flow as air density increases with turbocharger pressure, tending to hold a constant fuel/air ratio. However, no compensation for ambient air temperature effects on air density are made, as the aneroid is insensitive to temperature.

From the pump, fuel flow to the engine is metered by an orifice which is directly linked to the air throttle. The size of the orifice is a function of the throttle position. Orifice size tends to increase as the throttle is opened, increasing fuel flow as manifold pressure and engine airflow increase. Fuel pressure downstream of the throttle valve (metered fuel pressure) is fed to the manifold valve and nozzle. The rate of fuel flow entering the cylinders depends on the fluid pressure





**FIGURE 3. FUEL INJECTION SYSTEM HARDWARE**

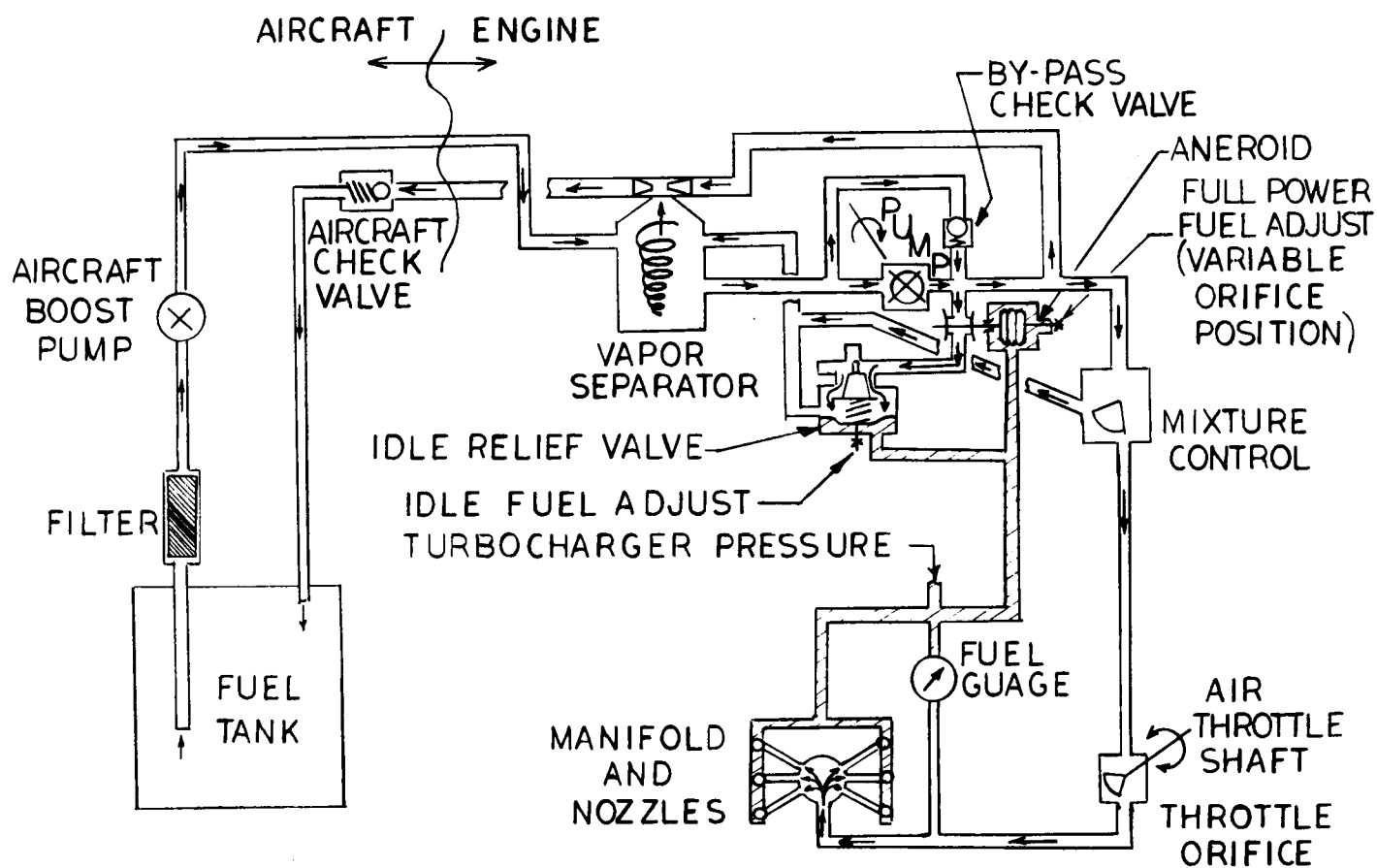


FIGURE 4. FUEL INJECTION SYSTEM SCHEMATIC

of the fuel relative to the reference pressure of the nozzles. For turbocharged engines, turbocharger discharge pressure is used as a nozzle reference pressure. The manifold valve, nozzle lines, and nozzles are factory calibrated as a unit so that fuel flow rate is a set function of metered fuel pressure (figure 5). The function of the manifold valve is to distribute fuel flow to the individual fuel nozzles and to abruptly chop the fuel flow when metered fuel pressure drops below the idle cutoff level.

Fuel/air mixture ratio is manually leaned by the pilot by opening a fuel pump bypass valve which reduces fuel pump discharge pressure. Since this action reduces fuel flow without affecting airflow, the fuel/air ratio is reduced.

#### Description of the Fuel System Model

Simulation of the fuel injection system involves the solution of a fluid flow network to determine the flow rate and pressures within the system. The approach used to simulate the fuel system is described in detail in reference 3. Using this approach, the flow versus pressure drop relationship for each component of the system was first established using an equation or curve fit based on component flow testing. Next, a set of governing equations was established using two basic hydraulic principles:

$$\begin{array}{ll} \text{Flow continuity} & (1) \\ \Sigma(\text{flows entering a junction}) = 0 & \end{array}$$

$$\begin{array}{ll} \text{Continuity of Potential} & (2) \\ \Sigma(\text{pressure changes across a closed flow path}) = 0 & \end{array}$$

These equations form a set of nonlinear simultaneous equations which can be solved with the help of a computer iterative technique. The technique employed, Rosenbrock's algorithm, uses initial guesses for the unknowns and improves the guesses using the set of simultaneous equations. Successive iteration leads to a set of pressures and flow rates which satisfy equations 1 and 2. The accuracy of the initial guesses is not critical and satisfactory solutions can be obtained within about 5,000 iterations.

The fuel system model employed is shown in figure 6. There are 11 unknowns for the system, six pressures and five flow rates:

P1 - Pump inlet Pressure, X(1)  
 P2 - Pump discharge pressure, X(2)  
 P3 - Fuel metered pressure, X(3)  
 P4 - Nozzle inlet pressure, X(4)  
 P6 - Variable orifice discharge pressure, X(5)  
 P7 - Vapor return line pressure, X(6)  
 WA - Supply line flow rate, X(7)  
 WB - Pump flow rate, X(8)  
 WC - Vapor separator flow rate, X(9)  
 WD - Variable orifice flow rate, X(10)  
 WE - Fuel system output flow rate, X(11)

Of course, one of the unknowns is the desired fuel output of the system, WE. In order to solve for the 11 unknowns, there must be a set of 11 simultaneous equations. These are composed of two flow continuity equations and nine continuity of potential equations:

$$\begin{array}{l} \text{Flow continuity at junction 0} \\ \text{WA-WE-WC=0} \end{array} \quad (3)$$

$$\begin{array}{l} \text{Flow continuity at junction 1} \\ \text{WB-WA-WD=0} \end{array} \quad (4)$$

$$\begin{array}{l} \text{PAMB-P1-(DP)}_{\text{SL}} = 0 \\ \text{Where (DP)}_{\text{SL}} = \text{Supply Line Pressure drop} \\ \text{PAMB} = \text{Ambient pressure (known)} \end{array} \quad (5)$$

$$\text{P2-P1- Pump Pressure Rise} = 0 \quad (6)$$

$$\begin{array}{l} \text{P2-P6- Variable Orifice Pressure} \\ \text{Drop} = 0 \end{array} \quad (7)$$

$$\begin{array}{l} \text{P6-P1- Idle Relief Valve Pressure} \\ \text{Drop} = 0 \end{array} \quad (8)$$

$$\begin{array}{l} \text{P2-P7- Vapor Separator Pressure} \\ \text{Drop} = 0 \end{array} \quad (9)$$

$$\begin{array}{l} \text{P2-P3- Control Unit Pressure} \\ \text{Drop} = 0 \end{array} \quad (10)$$

$$\begin{array}{l} \text{P3-P4- Mainfold Valve Pressure} \\ \text{Drop} = 0 \end{array} \quad (11)$$

$$\begin{aligned} \text{P4-P5- Nozzle Pressure Drop} &= 0 & (12) \\ \text{Where P5} &= \text{Turbocharger discharge} \\ &\text{pressure (known)} \end{aligned}$$

$$\begin{aligned} \text{P7-PO- Return Line Pressure Drop} &= 0 & (13) \\ \text{Where PO} &= \text{Ambient pressure (known)} \end{aligned}$$

These 11 equations were formed into 11 separate computer sub-routines. Each subroutine is used to calculate the value of one of the sums based on assumed values for the 11 unknowns and known boundary values. The correct assumptions for the unknowns will yield 11 sums which each equal zero. To find a solution to the problem using Rosenbrock's algorithm, an objective function is formed using the remainder terms from each of the 11 functions:

$$F = F_1^2 + F_2^2 + \dots + F_{11}^2$$

Where  $F_1 = \text{WA-WE-WC}$

$F_2 = \text{WB-Wa-WD}$

$F_3 = \text{PO-P1} - \text{Supply line pressure drop}$

.

.

.

$F_{11} = \text{P7-PO- Return line pressure drop}$

After calculating the objective function (F) based on assumptions for the 11 variables, new values for the unknowns are formed within the algorithm. A new value of the objective function is calculated using the 11 subroutines. If the magnitude of the objective function is less than the previous value, the new values for the unknowns are accepted. Successive iterations are continued until the objective function is reduced to a small positive value. The magnitude of the objective function is a measure of the error of the solution, and can be used as a criteria for convergence. For this study, the maximum value of the objective function was set at 0.001 which gave flow rates correct to within approximately 0.10 pounds per hour.

The use of subroutines within the computer code gives the simulation the flexibility needed to allow evaluation of modifications to the fuel system. Changes which would require extensive bench and flight testing of the entire fuel system

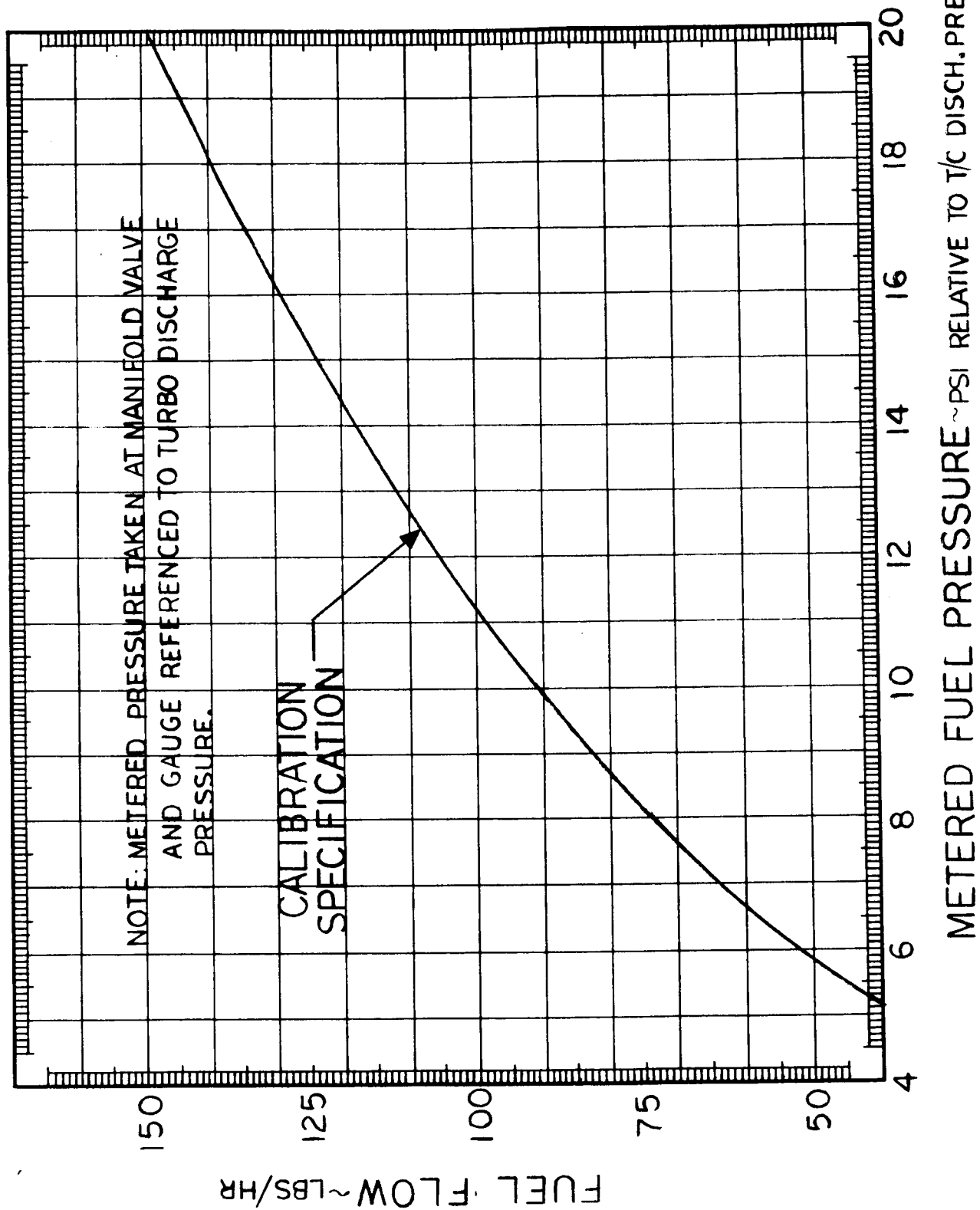
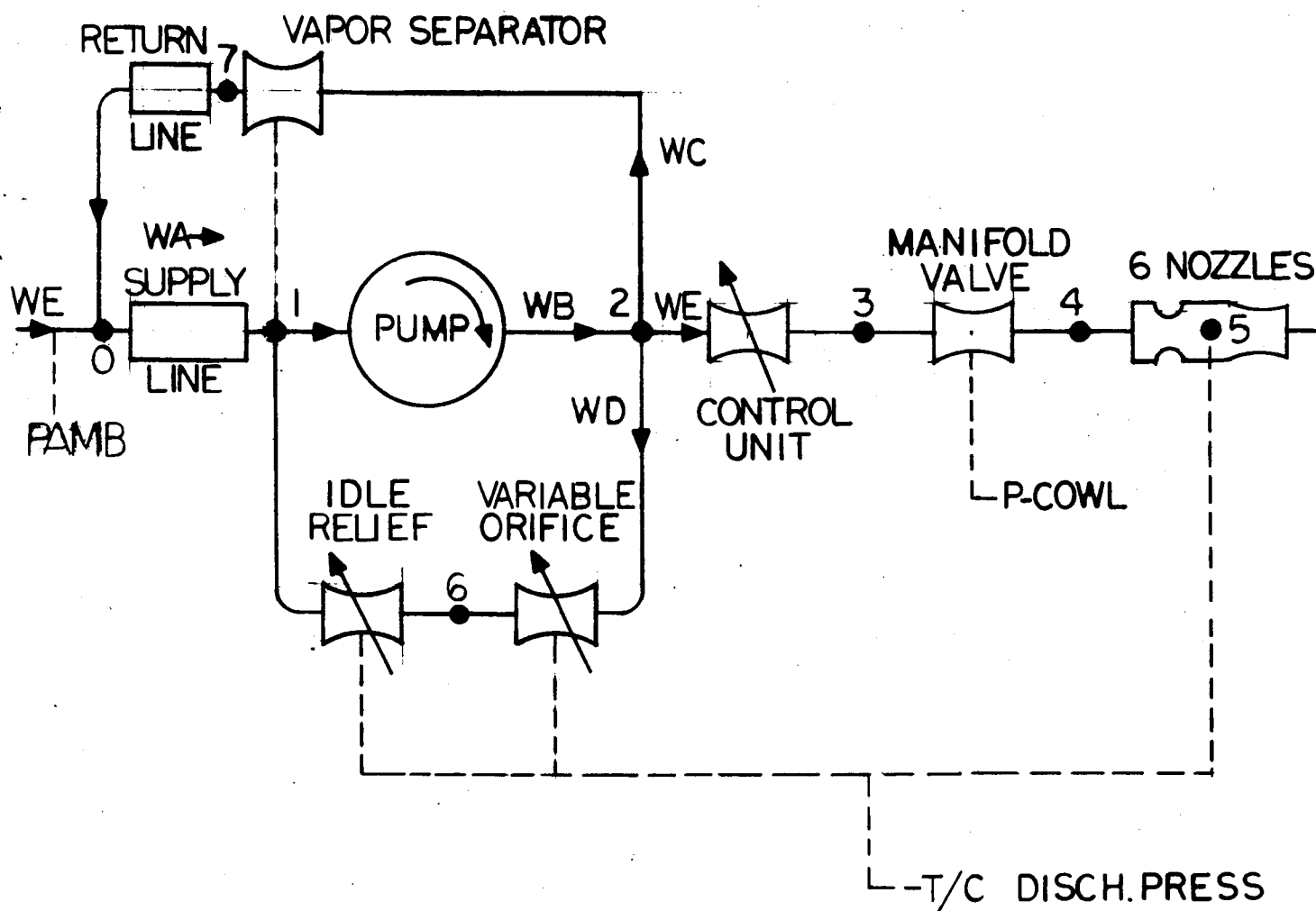


FIGURE 5. METERED FUEL ASSEMBLY CALIBRATION



**FIGURE 6. FUEL SYSTEM MODEL**

can be evaluated by bench testing only the new component to establish the flow/pressure relationship. Evaluation of the entire fuel system can then be made using the simulation by modifying or adding subroutines.

Operating environment (temperature and pressure), engine inputs, and aircraft installation effects on fuel system output can be easily evaluated using the simulation.

Evaluation of equations 3 thru 13 require calculation of the pressure changes that occur in each component based on the known boundary conditions and assumed values for the unknowns. Each component of the system was tested to determine its fluid behavior. A description of the model used for each fuel system component in the current system is given in the sections which follow. A complete Fortran IV computer listing of the simulation is given in the appendix.

1) Flow Continuity Equations

Flow continuity is easily calculated using equations 3 and 4 and assumed values for the unknown flows:

$$\begin{aligned} F1 &= X(7) - X(11) - X(9) \text{ (Continuity at junction 0)} \\ F2 &= X(8) - X(7) - X(10) \text{ (Continuity at junction 1)} \end{aligned}$$

The values of F1 and F2 are a measure of the error of the assumed values for variables X(7) thru X(11), corresponding to the five unknown flow rates of the system.

2) Supply and Return Lines

The pressure drop through the fuel lines was calculated using an appropriate friction factor and the methods given in reference 4. Line pressure drop is calculated as:

$$\Delta P = K_f * Q + \frac{\rho * (Z1 - Z0)}{1728}$$

$$\text{Where } K_f = FF * L/D + K_o$$

$$FF = 64./Re \text{ for laminar flow (Re < 3000)}$$

$$FF = \text{Value from Moody diagram (figure 7) for turbulent flow}$$

$$L = \text{Line length (inches)}$$

$$D = \text{Line diameter (inches)}$$



$K_o$  = Dimensionless experimental coefficient accounting for head loss in bends, valves, fittings, etc. Available in numerous handbooks, (reference 4)

Re = Reynolds number

$$Re = \frac{W \times D}{\mu \times A} \times \frac{12.}{3600.}$$

$\mu$  = Fluid viscosity,  $Lb_m / ft\text{-}sec$

$\rho$  = Density of fluid ( $lbm/ft^3$ )

ZO = Elevation of line at fluid inlet (inches)

Z1 = Elevation of line at flow exit (inches)

Q = Fluid dynamic head (psi)

$$= 1/2 * \frac{W * |W| * 144.}{(3600)^2 (\rho) (A^2) (32.2)}$$

W = Fluid flow rate (pph)

A = Cross-sectional area of line ( $in^2$ )

The friction factor (FF) for turbulent flow is a function of the line surface roughness relative to the line diameter and Reynolds number, as explained in reference 4. Surface roughness (EPSP) was estimated to be 125. microinches.

Fuel viscosity and density for low lead 100 Octane (LL100) aviation gasoline (Avgas) are built in functions of temperature as shown in figures 8 and 9 (reference 5).

For turbulent flow, friction factor is determined by interpolation of figure 7, which was built into the computer code. The friction factor for laminar flow is given by the equation:

$$FF = 64./Re \quad (\text{reference 4})$$

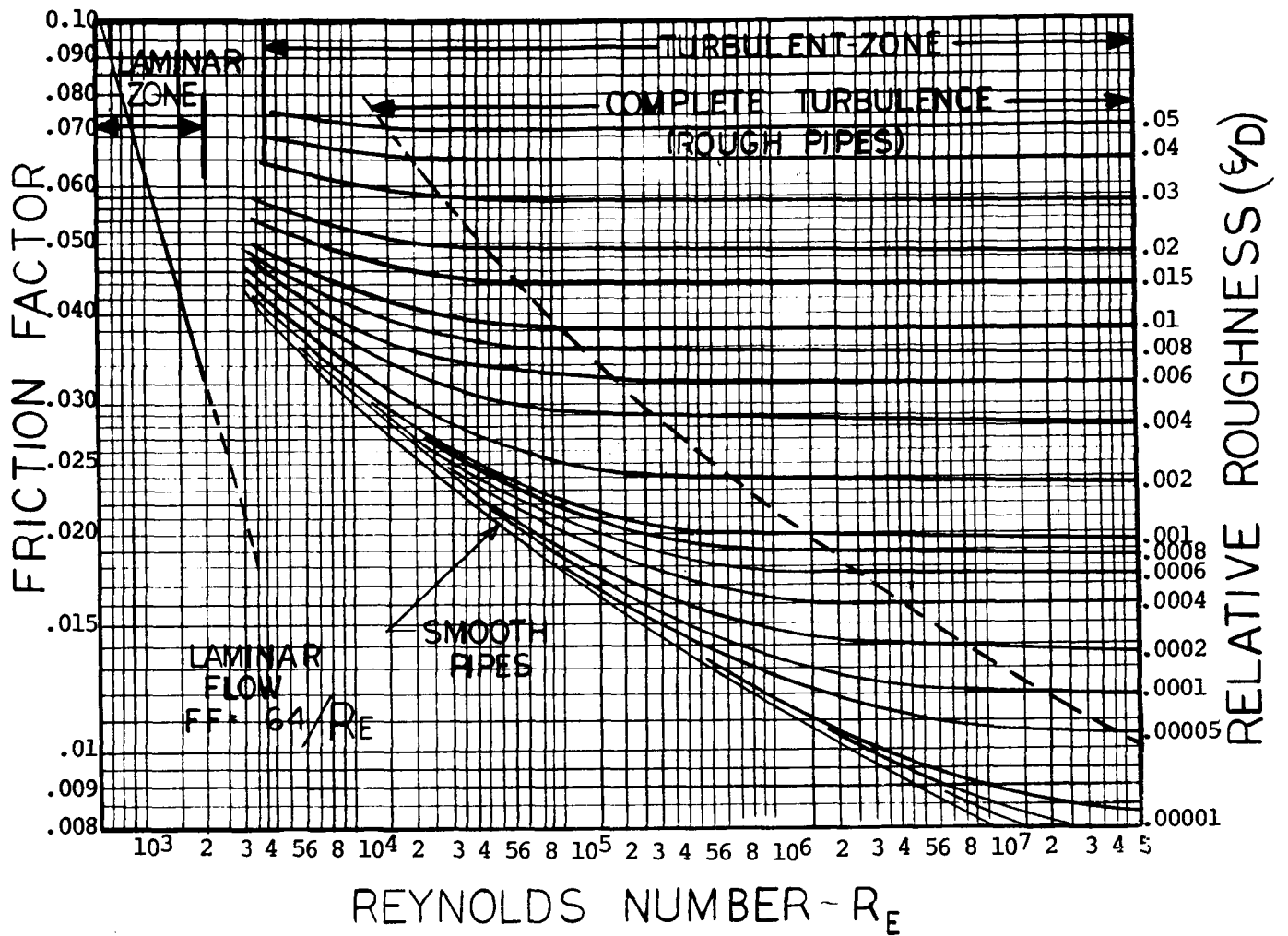


FIGURE 7. FRICTION FACTORS FOR FULLY DEVELOPED FLOW

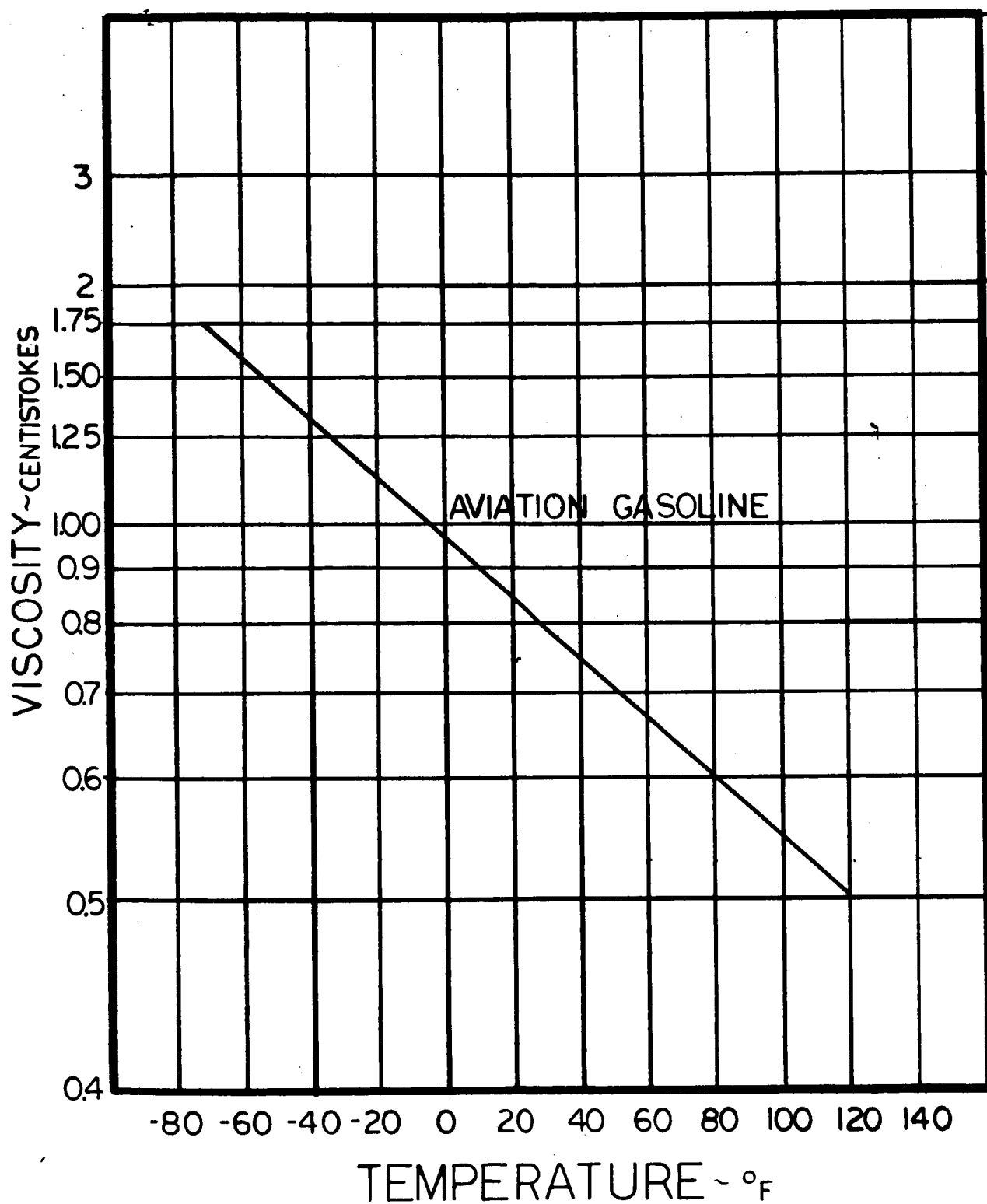


FIGURE 8. VARIATION OF FUEL VISCOSITY WITH TEMPERATURE

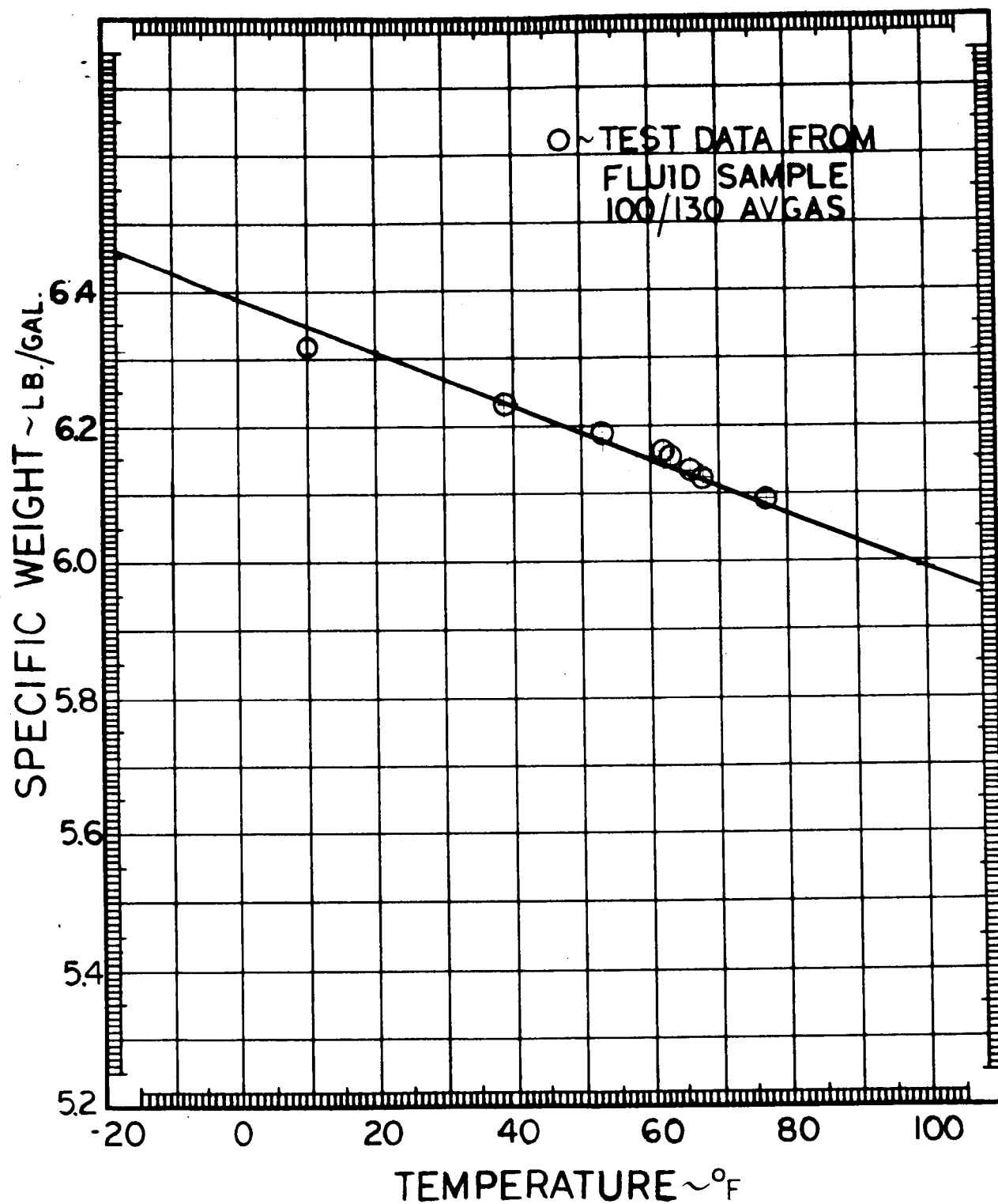


FIGURE 9. SPECIFIC WEIGHT OF 100/130 AVGAS

### 3) Fuel Pump

Bench tests were used to establish the fluid behavior of the rotary vane pump. Data from these tests is plotted in figures 10 and 11. Cross plots of the data show that pump output is proportional to pump speed for a given pump pressure rise (figure 12). An equation for the pump output was developed based on pump displacement and experimentally determined flow rate:

$$W = \left( \frac{\eta * \rho * DISP}{1728.} \right) * (60 * N) - F(\Delta P)$$

Where  $\eta$  = pump efficiency (93.7 percent for the pump tested)

$\rho$  = fluid density

DISP = pump displacement (in<sup>3</sup>)

N = pump speed (RPM)

F( $\Delta P$ ) = pump leakage flow rate (PPH) (figure 13)

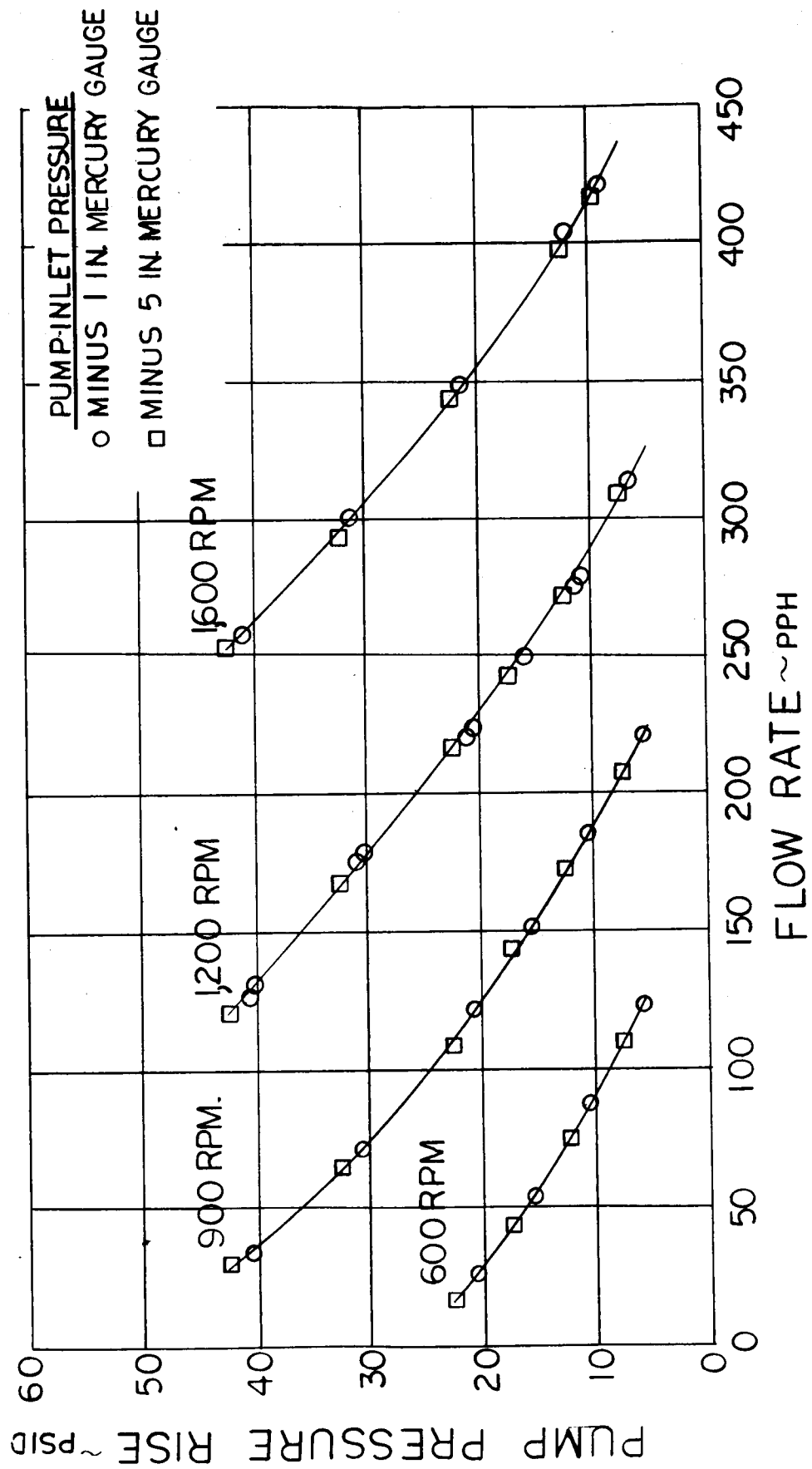
Pump leakage is due to internal pump flow used for bearing lubrication plus vane leakage. This flow is independent of pump speed and is a function of the pressure rise across the pump and vane tolerances as shown in figure 13.

### 4) Variable Orifice

A cross-sectional view of the variable orifice is shown in figure 14. Pressure loss through the variable orifice depends on the position of the orifice rod relative to the body of the orifice. Figure 15 shows the effect of varying flow rate and orifice position on orifice pressure loss as determined from bench tests. For constant orifice position, orifice pressure loss is proportional to the square of the flow rate. Orifice flow area varies as shown in figure 16, calculated from the known orifice and rod radii:

$$A = \pi \left[ (R_o)^2 - (R_r)^2 \right]$$

Where  $R_o$  = radius of unblocked orifice  
 $R_r$  = radius of orifice rod



**FIGURE 10. VANE PUMP CALIBRATION**

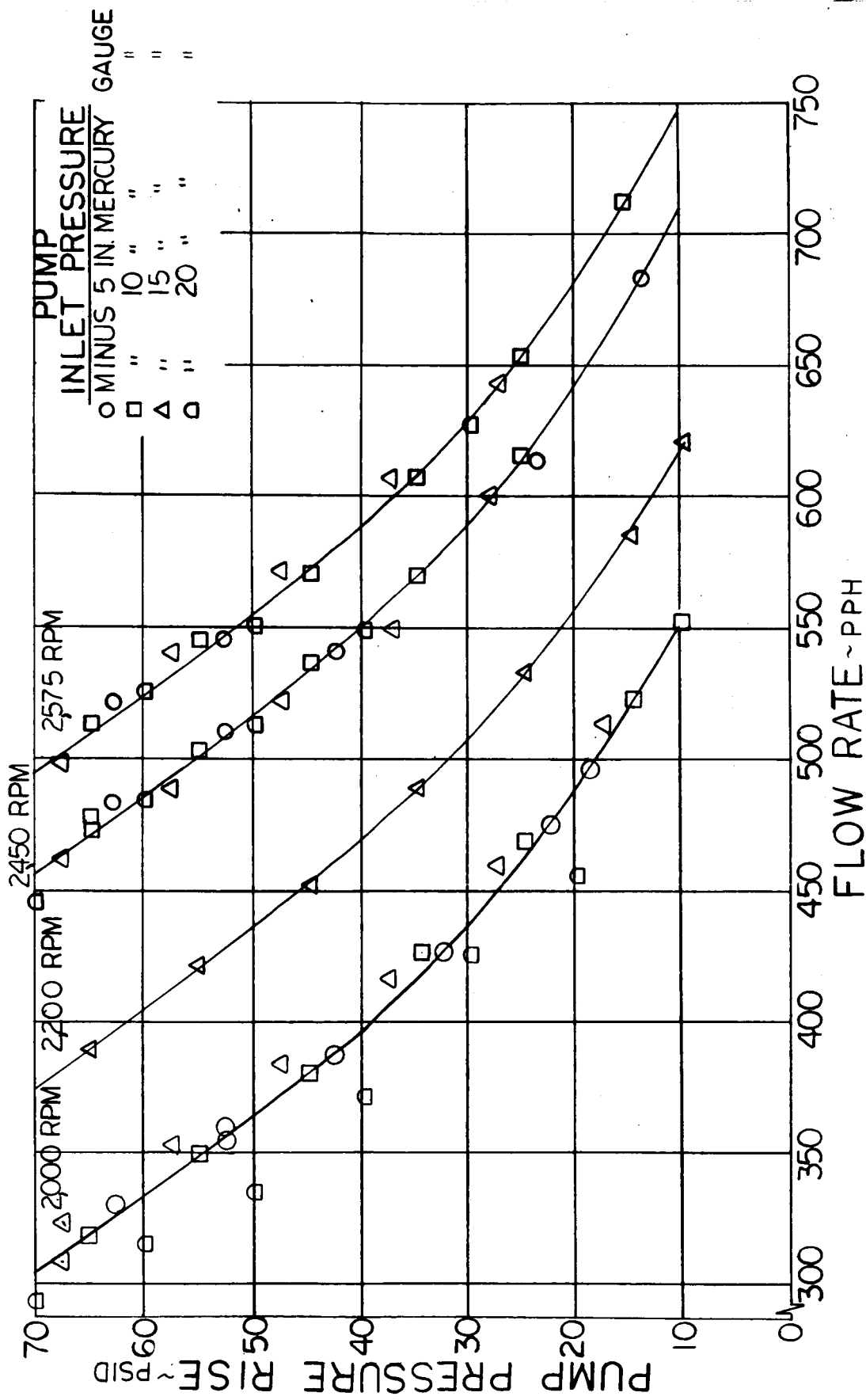


FIGURE 11. VANE PUMP CALIBRATION

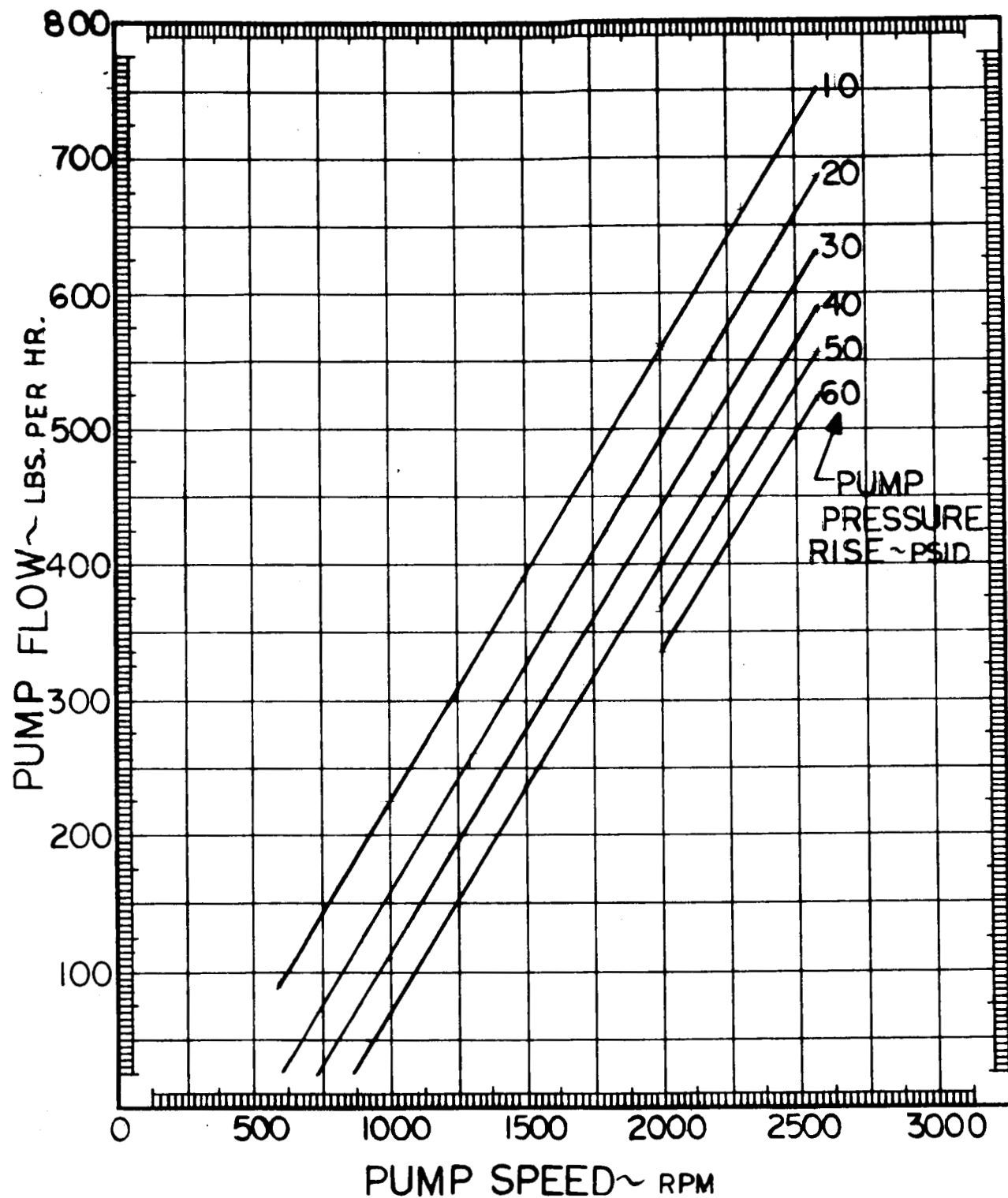


FIGURE 12. VANE PUMP FLOW MAP



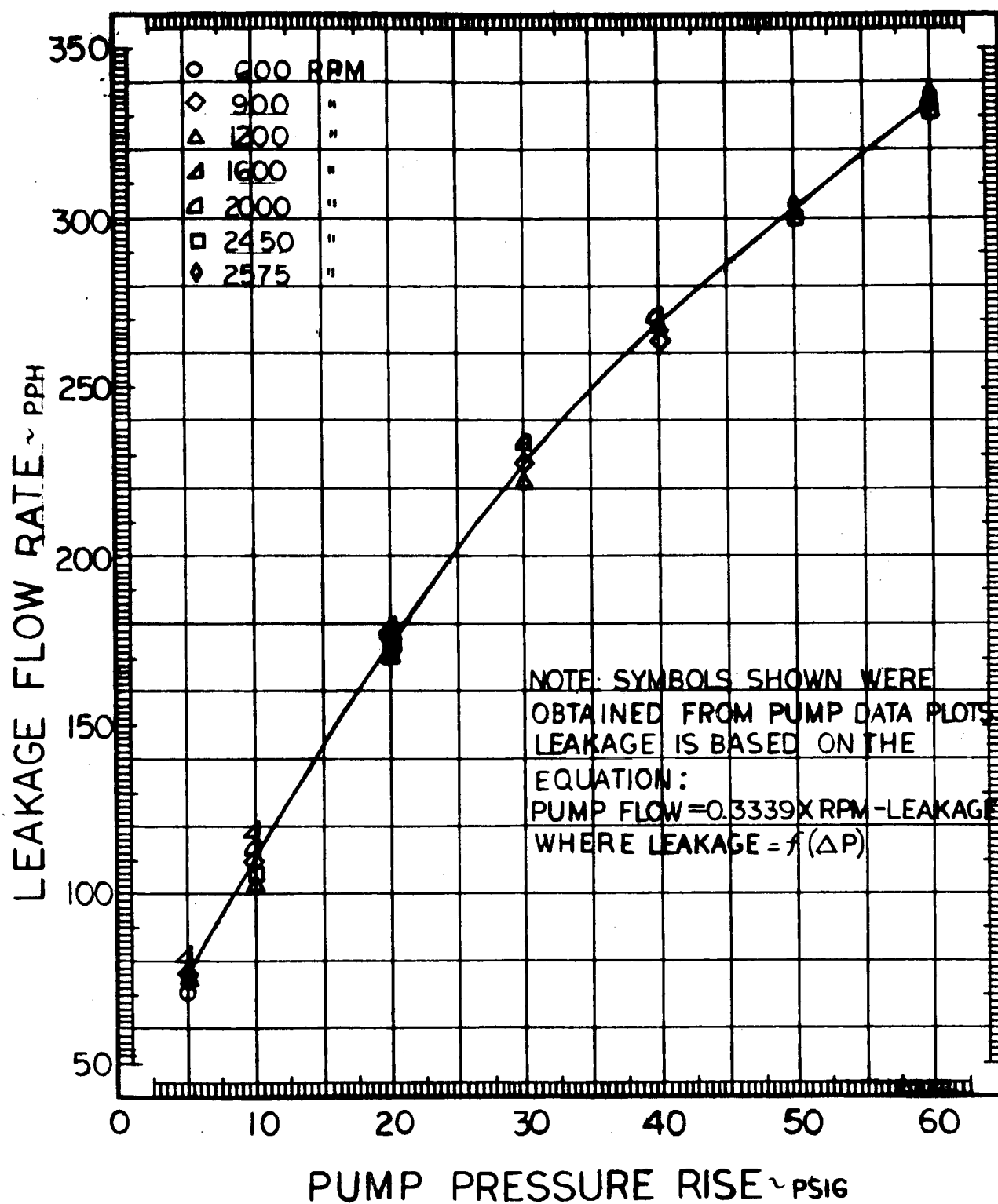
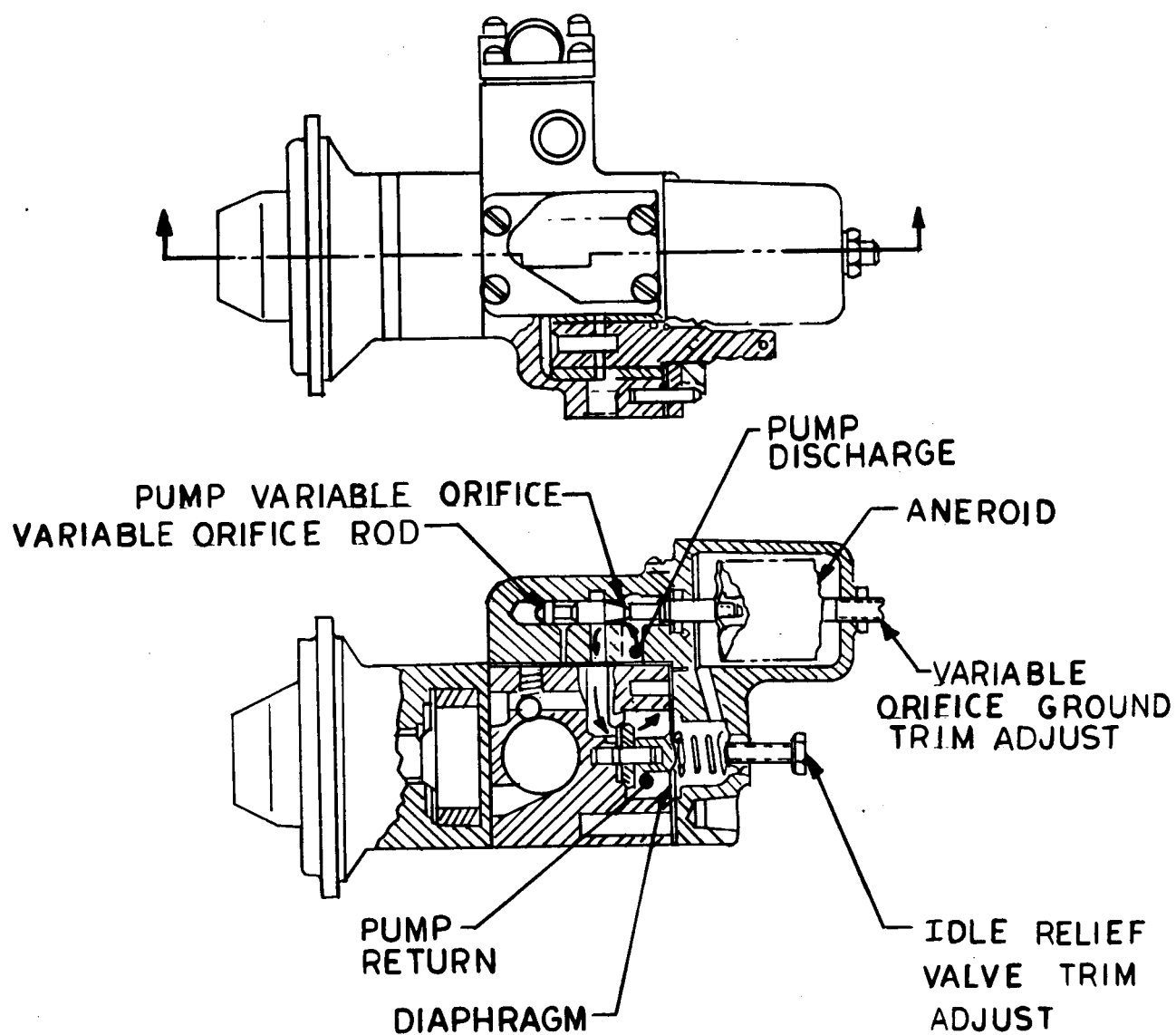


FIGURE 13. VANE PUMP LEAKAGE



**FIGURE 14. FUEL PUMP ASSEMBLY**

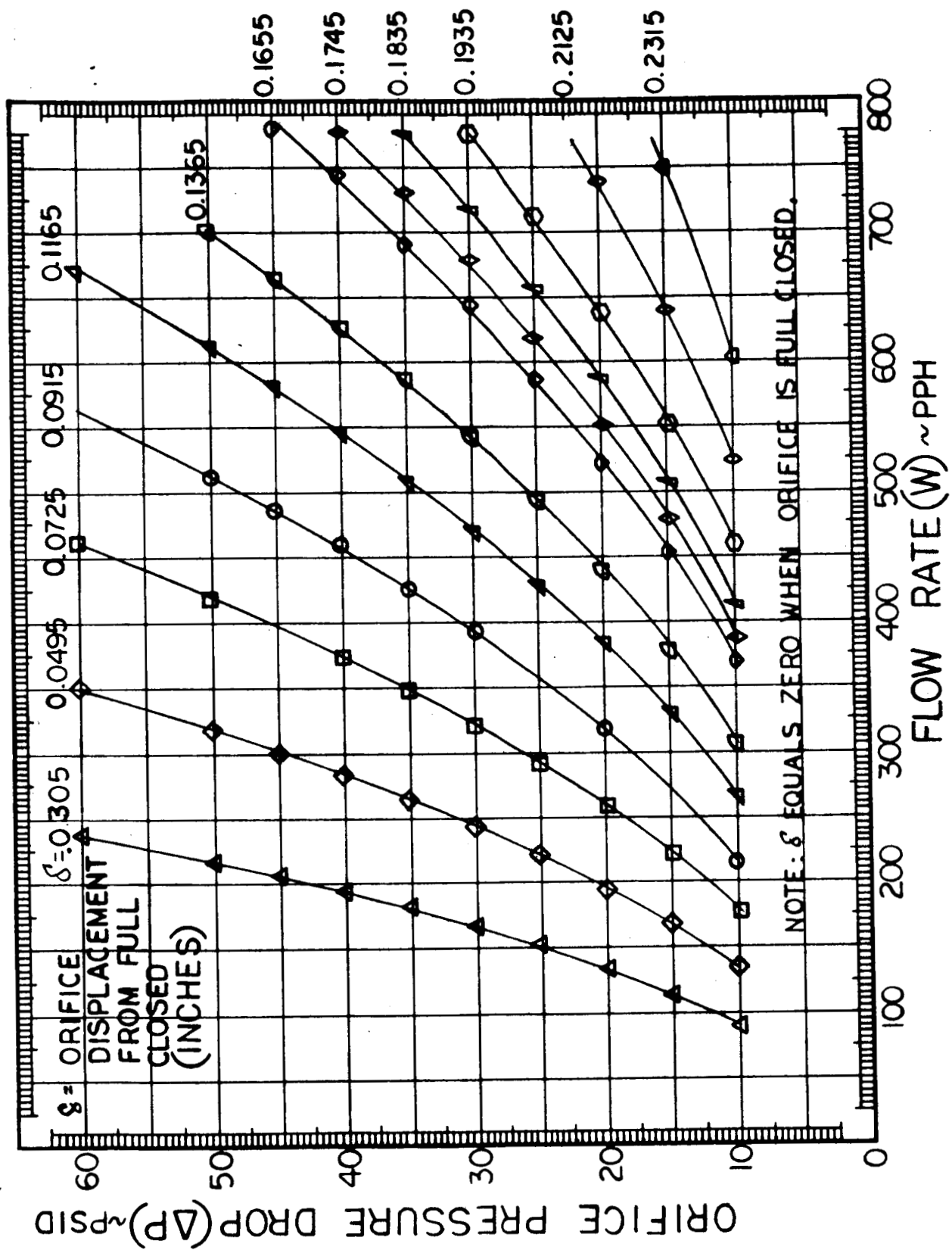


FIGURE 15. VARIABLE ORIFICE CHARACTERISTICS

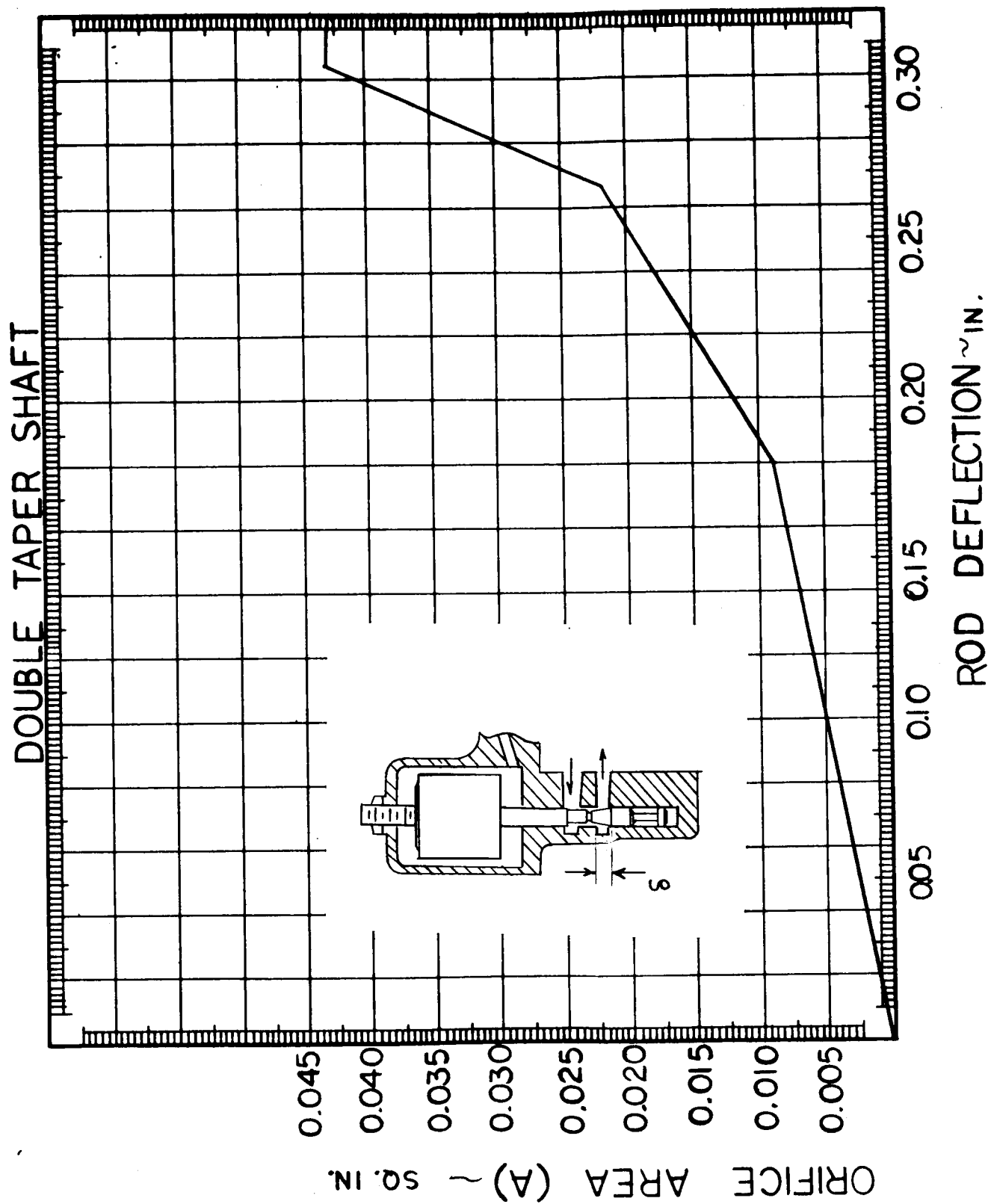


FIGURE 16. VARIABLE ORIFICE FLOW AREA

Based on the experimental data and analytical area calculations, an orifice dimensionless K-factor can be determined as a function of orifice area as shown in figure 17. Orifice pressure loss is then calculated using:

$$DP = K * Q$$

Where

$Q$  = Orifice dynamic head (psi)

$$= \frac{1/2 \rho * V^2}{(32.3)(144.)}$$

and  $V$  = mean flow velocity

$$V = \frac{W * 144.}{\rho * A * 3600.}$$

$W$  = Flow rate (pph)

$\rho$  = Density (lbm/ft<sup>3</sup>)

$A$  = Orifice area (in<sup>2</sup>)

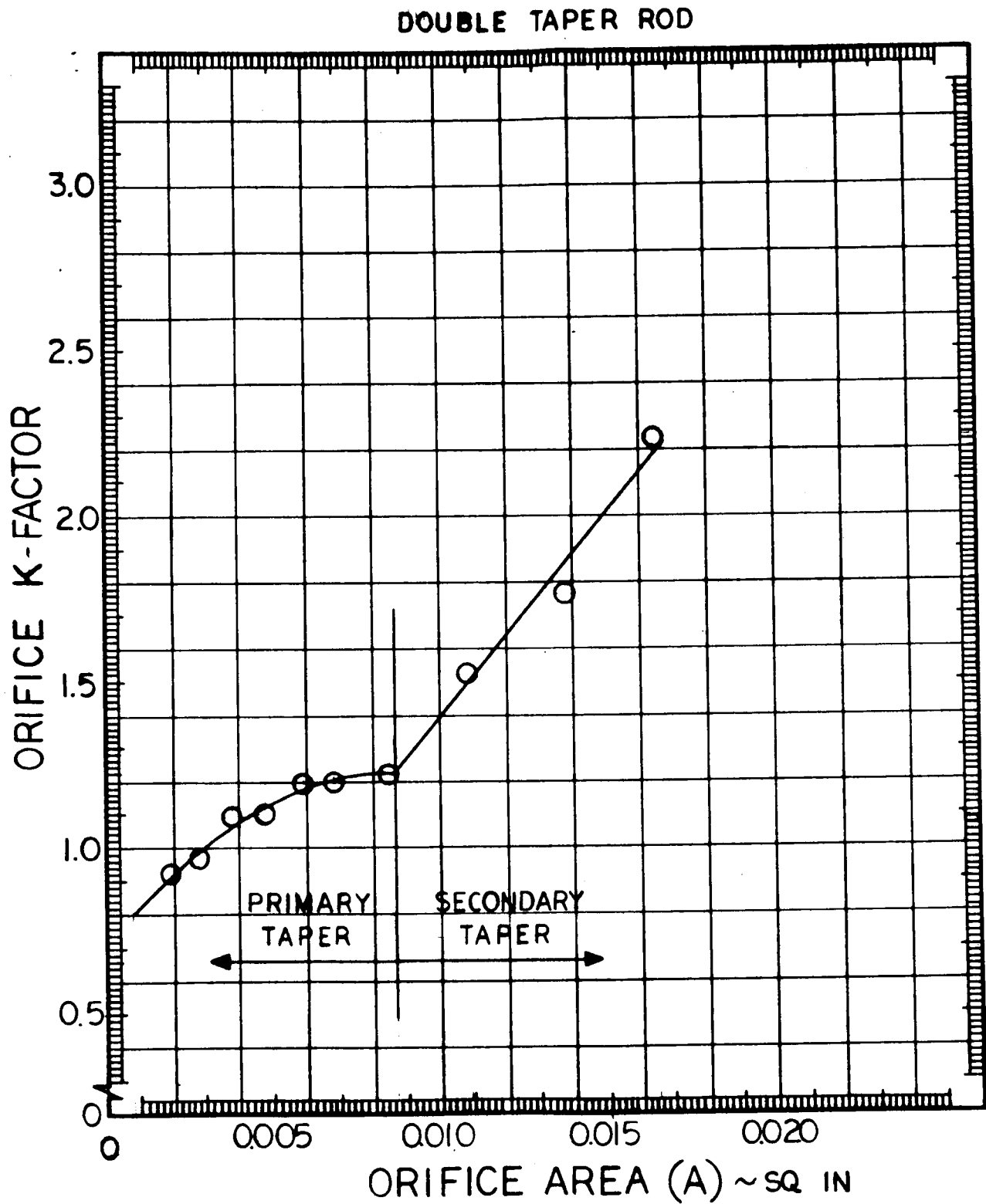
This equation gives an orifice pressure drop proportional to the square of the orifice flow rate, in agreement with the data in figure 15.

In order to determine the orifice pressure loss, the position of the orifice must be known. The effect of reference pressure on aneroid movement is shown in figure 18. Tests indicate that changes in temperature do not produce significant aneroid movement. Changes in temperature from 80° F to 150° F cause aneroid movements on the order of 0.005 inches. Aneroid temperature insensitivity is ideal, since the temperature of the aneroid is not representative of induction air temperature.

Fuel pressure on the orifice rod produces movement of the rod, since the aneroid behaves as a linear spring (figure 19). Because of the interaction of fuel pressure forces on aneroid movement and vice versa, orifice pressure loss must be determined by iteration. The final orifice rod position is given by:

$$\delta = \delta \text{ adj.} + AMS (P_{\text{adj}} - P_5) - \frac{RF}{K} \quad (14)$$

Where  $\delta \text{ adj}$  = Orifice rod adjusted position



**FIGURE 17. VARIABLE ORIFICE LOSS FACTOR**

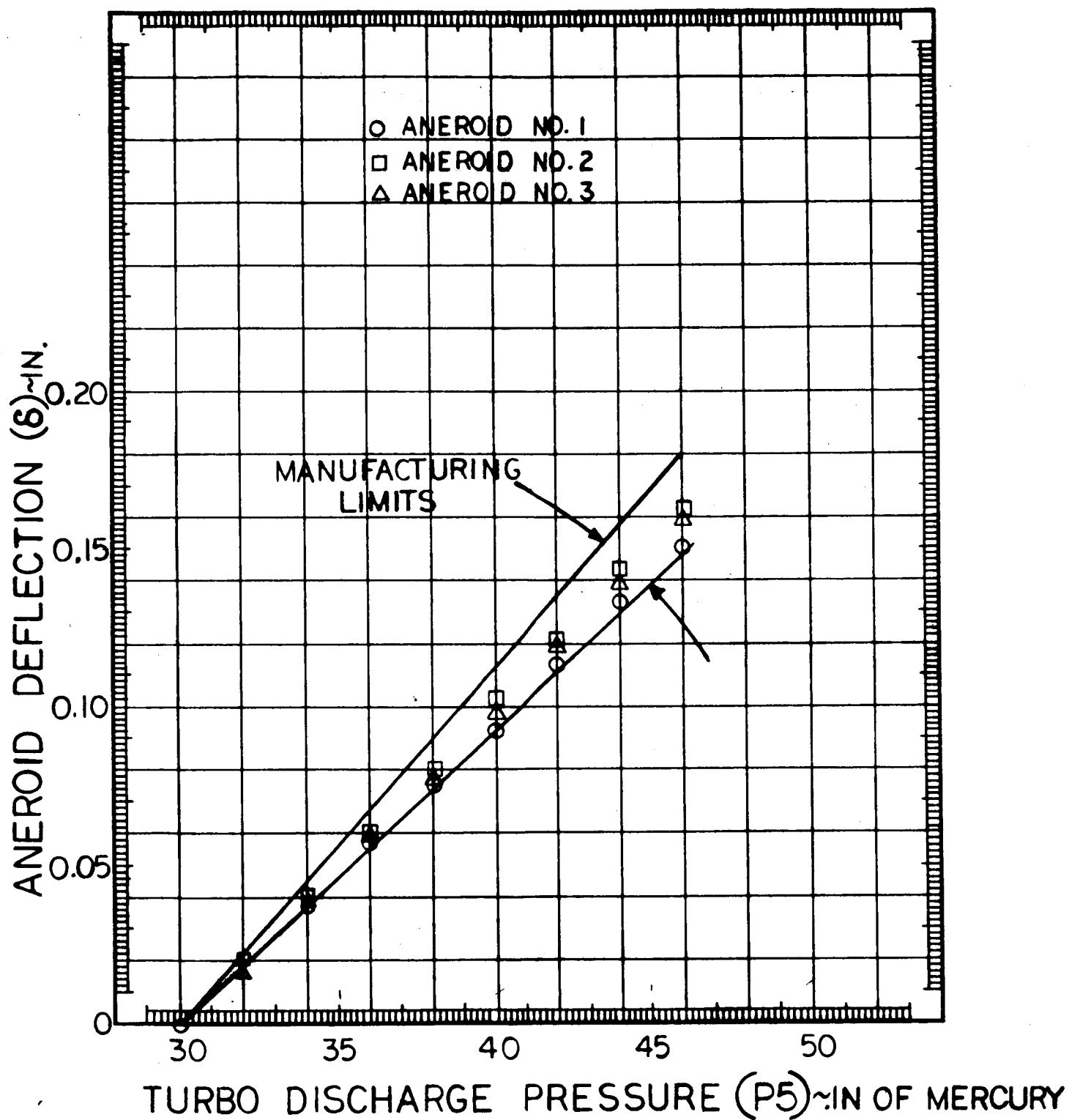


FIGURE 18. ANEROID TEST RESULTS

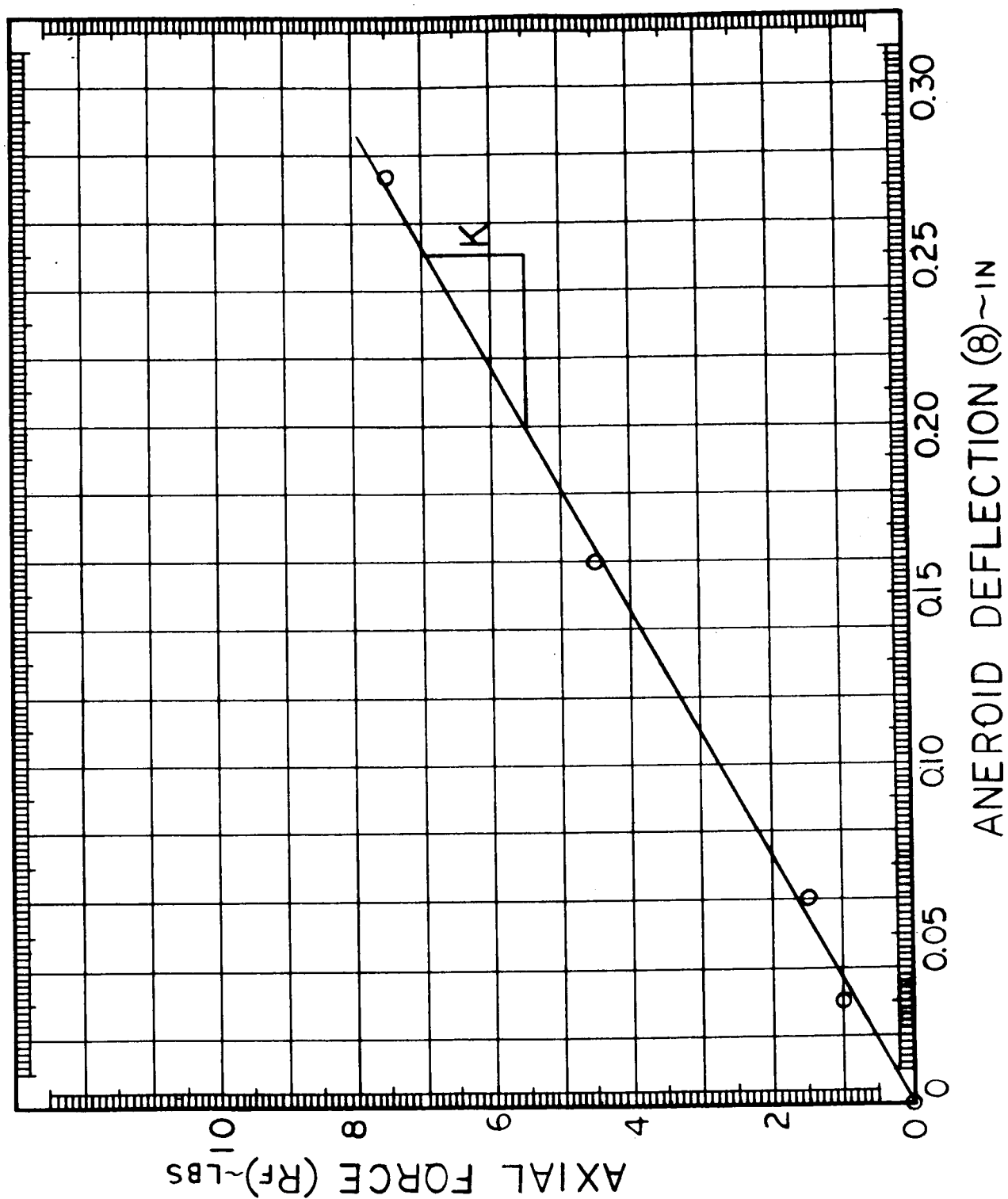


FIGURE 19. ANEROID DEFLECTION DUE TO AXIAL FORCE



- $P_{adj}$  = Turbo discharge pressure when orifice was adjusted  
 $P_5$  = Turbo discharge pressure for present operating conditions  
 $AMS$  = Slope of aneroid movement versus pressure (figure 18)  
 $K$  = Spring constant of the aneroid (figure 19)  
 $RF$  = Fuel pressure force on variable orifice rod

Orifice position ( $\delta$ ) as obtained from equation 14 is zero when the orifice is full closed (see figure 16).

#### 5) Idle Relief Valve

The idle relief valve is a spring-loaded valve used to set a minimum discharge pressure for the pump. A cross-sectional view of the relief valve is shown in figure 14. An adjustable spring and the action of the pump reference pressure (turbo discharge pressure,  $P_5$ ) on the valve diaphragm act to close the valve. The fluid pressure of the Avgas is higher at the valve inlet than at the valve discharge, producing a force across the valve orifice ( $A_v$ ) which tends to open the valve. Static equilibrium of forces on the valve yields equation 15 for the valve pressure drop:

$$\Delta P_v = \frac{K_s * \Delta LS + (P_5 - P_{ds}) A_e}{A_v} \quad (15)$$

Where  $\Delta P_v$  = Valve pressure drop ( $\text{lb}_f/\text{in}^2$ )

$A_v$  = Valve flow area ( $\text{in}^2$ )

$A_v = \pi R_l^2$

$R_l$  = Valve orifice radius (0.31 inches)

$P_5$  = Turbo discharge pressure ( $\text{lb}_f/\text{in}^2$ )

$P_{ds}$  = Valve downstream pressure ( $\text{lb}_f/\text{in}^2$ )

$A_e$  = Diaphragm effective area (sq in)

$K_s$  = Valve spring constant ( $\text{lb}_f/\text{inch}$ )

$\Delta LS$  = Ground-adjusted spring compression (inch)

Note that the valve pressure drop is independent of flow rate. This was found to be true from testing and is due to the rather large orifice area and relatively weak valve spring (low spring constant,  $K_s$ ). A small movement of the valve provides sufficient flow area for the required bypass flow (at relatively low pressure drop across the valve). Increase of the spring force due to this movement is small compared to the initial spring force typical of correct idle adjustment.

The unknown constants in equation 15 were determined from bench tests. Partial differentiation of this equation at constant turbo discharge and valve exit pressure gives:

$$\frac{d(\Delta P_v)}{d\Delta L_S} = \frac{K_s}{A_v} \quad (P_5 \text{ and } P_{ds} \text{ Constant})$$

which is the slope of the pressure drop versus spring adjustment curve given in figure 20. From the slope of the curve and known valve area, the spring constant was determined to be 13.7  $\text{lb}_f/\text{inch}$ .

Similarly, the effect of turbo discharge pressure on valve pressure drop at constant spring load and valve exit pressure can be expressed as:

$$\frac{d(\Delta P_v)}{d P_5} = \frac{A_e}{A_v} \quad \delta_{adj} \text{ and } P_{ds} \text{ Constant})$$

which is the slope of the line of data in figure 21. From the slope of the curve and known valve area, the diaphragm effective area was determined to be 0.334  $\text{in}^2$ . With the constants determined from bench tests, equation 15 can be used to calculate the relief valve pressure drop.

#### 6) Vapor Separator

The vapor separator pressure/flow relationship was determined experimentally and is given in figure 22. The internal passage connecting the pump discharge and inlet to the vapor separator was blocked and tapped to measure vapor separator flow rate. Flow rate was found to be insensitive to small changes in pump inlet pressure or vapor separator back pressure. Figure 22 was built into the computer model using a data block with linear interpolation between data points.

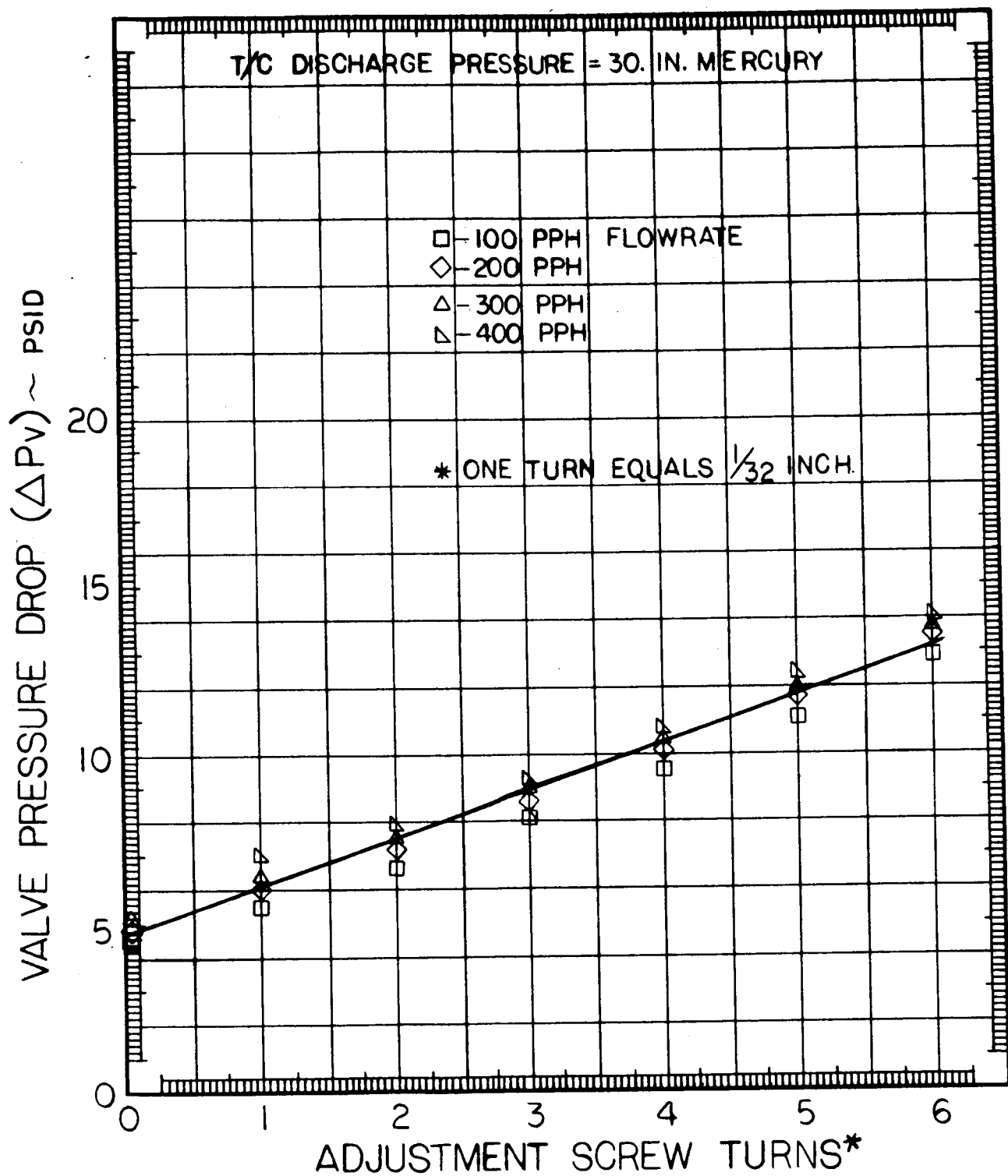


FIGURE 20. EFFECT OF RELIEF VALVE ADJUSTMENT  
ON VALVE PRESSURE LOSS

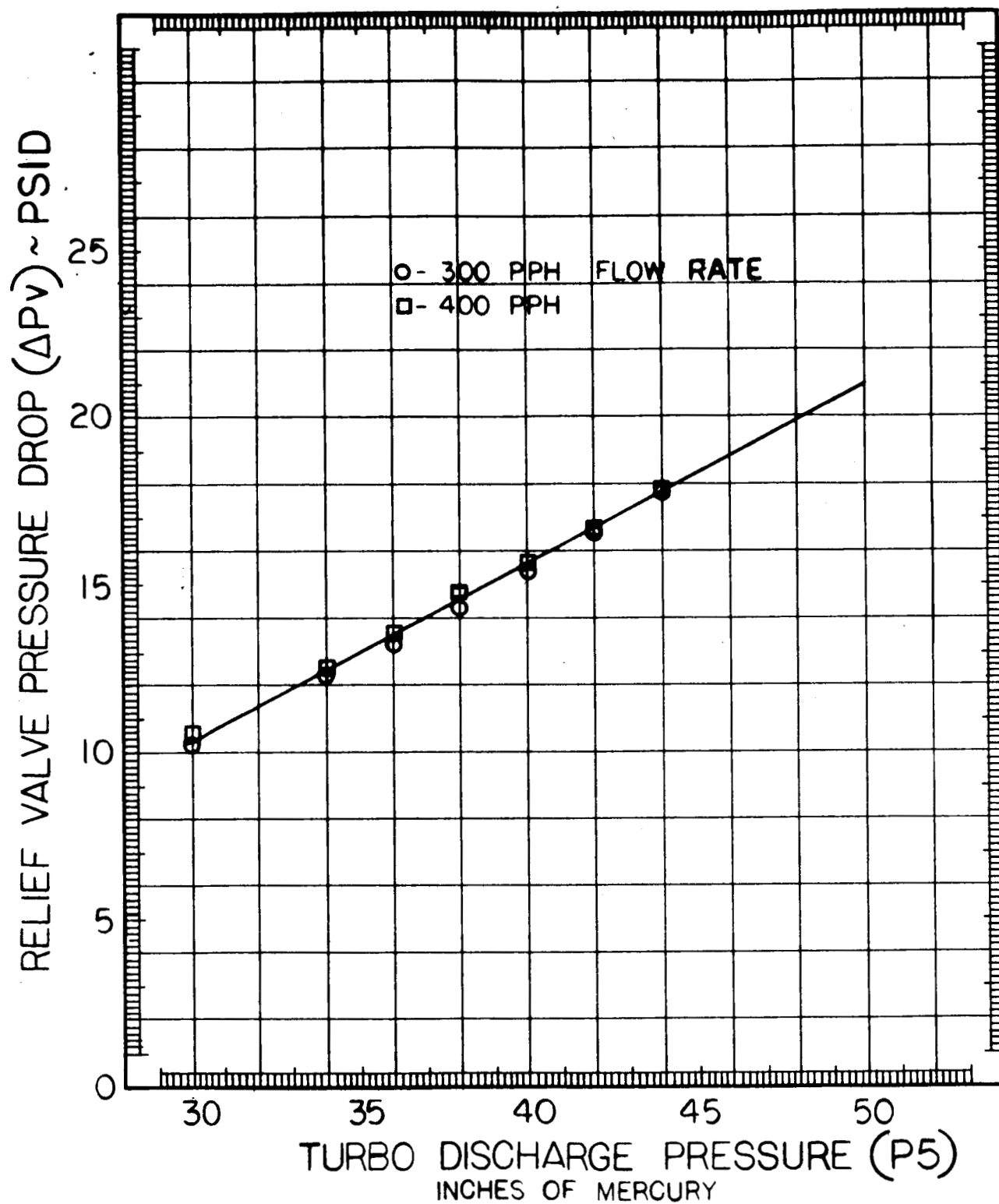


FIGURE 21. EFFECT OF TURBO DISCHARGE  
PRESSURE ON RELIEF VALVE

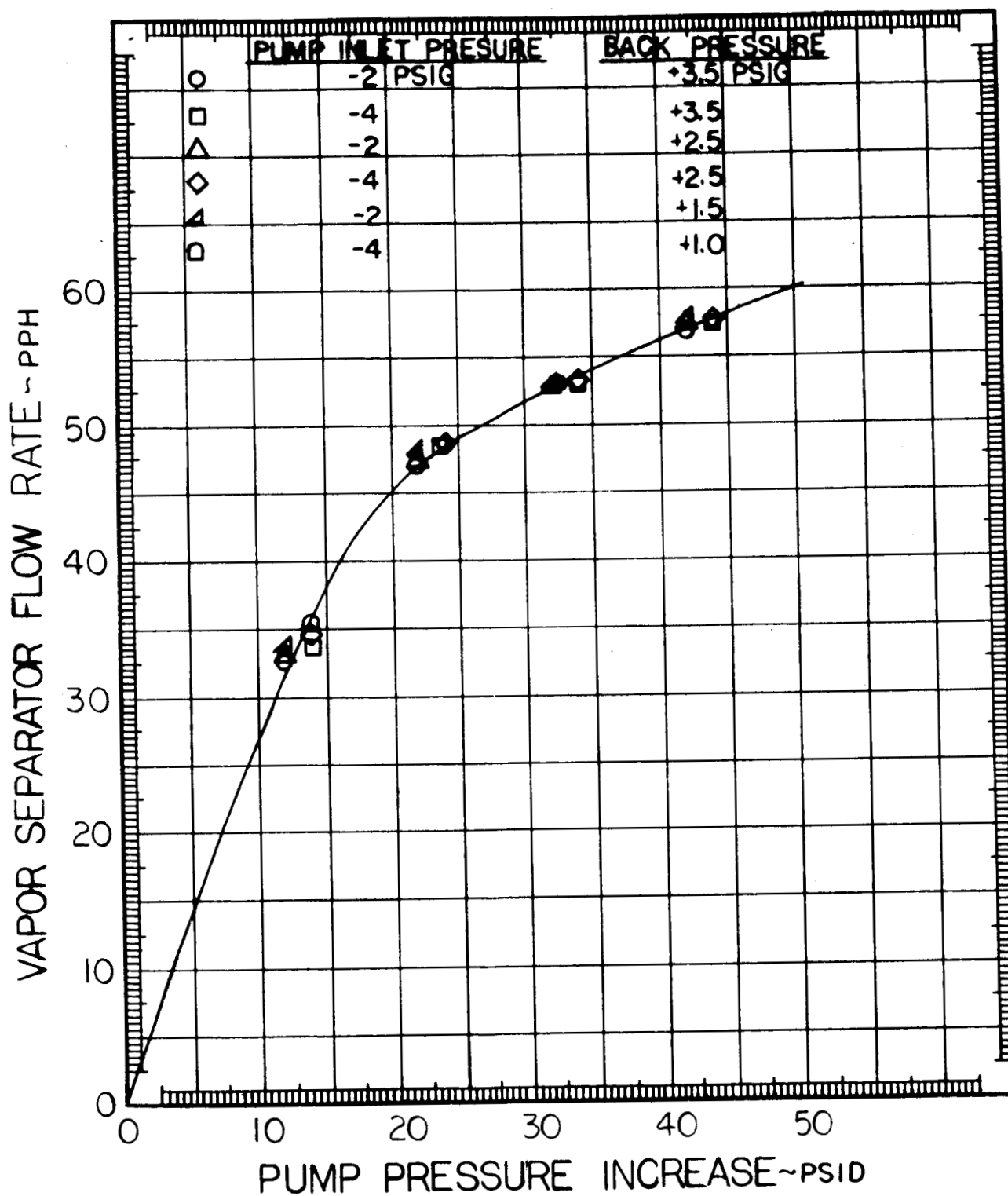


FIGURE 22. VAPOR SEPARATOR FLOW RATE

7) Throttle Orifice

Final fuel metering is accomplished by the throttle orifice, which is mechanically linked directly to the engine throttle. Orifice area is varied by the rotation of a cam in relation to an orifice, as shown in figure 23. A closed form solution for the orifice area as a function of throttle angle was found and is plotted in figure 24.

Throttle pressure losses as determined from bench testing are plotted in figure 25. Pressure losses for constant throttle setting are proportional to the square of the flow rate as indicated by the curves. Throttle pressure losses are given by:

$$\Delta P_t = K * Q$$

Where  $K = 1.5 =$  dimensionless experimental coefficient as determined from test

and  $Q =$  dynamic head

$$= \frac{1/2 \rho V^2}{(32.2)(144.)} \quad \text{psi}$$

$\rho =$  fluid density (lbm/ft<sup>3</sup>)

$V =$  velocity of fuel

$$V = \frac{W}{\rho A C_d} * \frac{144.}{3600.}$$

$W =$  Orifice flow rate (pph)

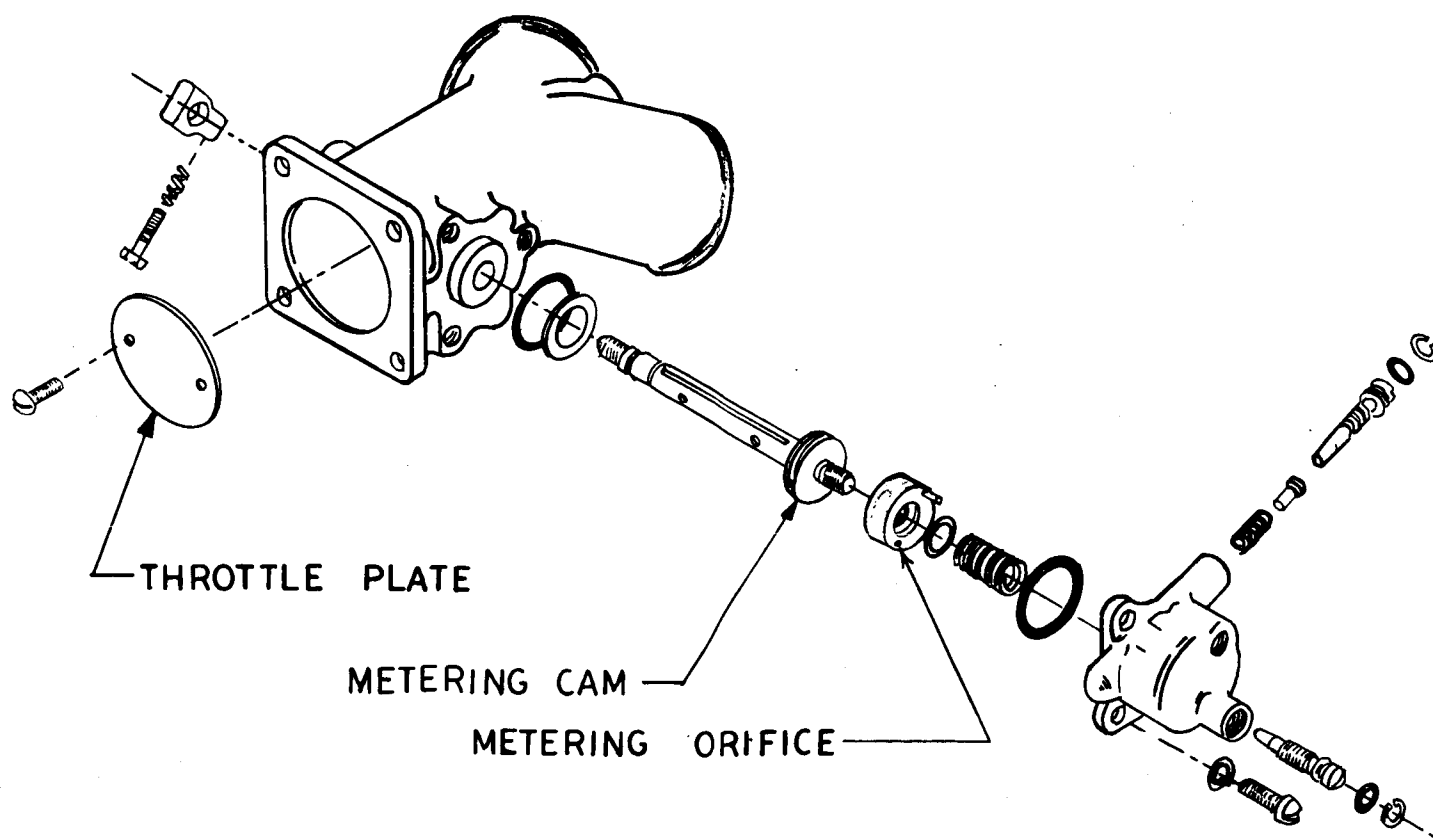
$A =$  Orifice physical area (in<sup>2</sup>) (figure 24)

$C_d =$  Orifice discharge coefficient  
(figure 26)

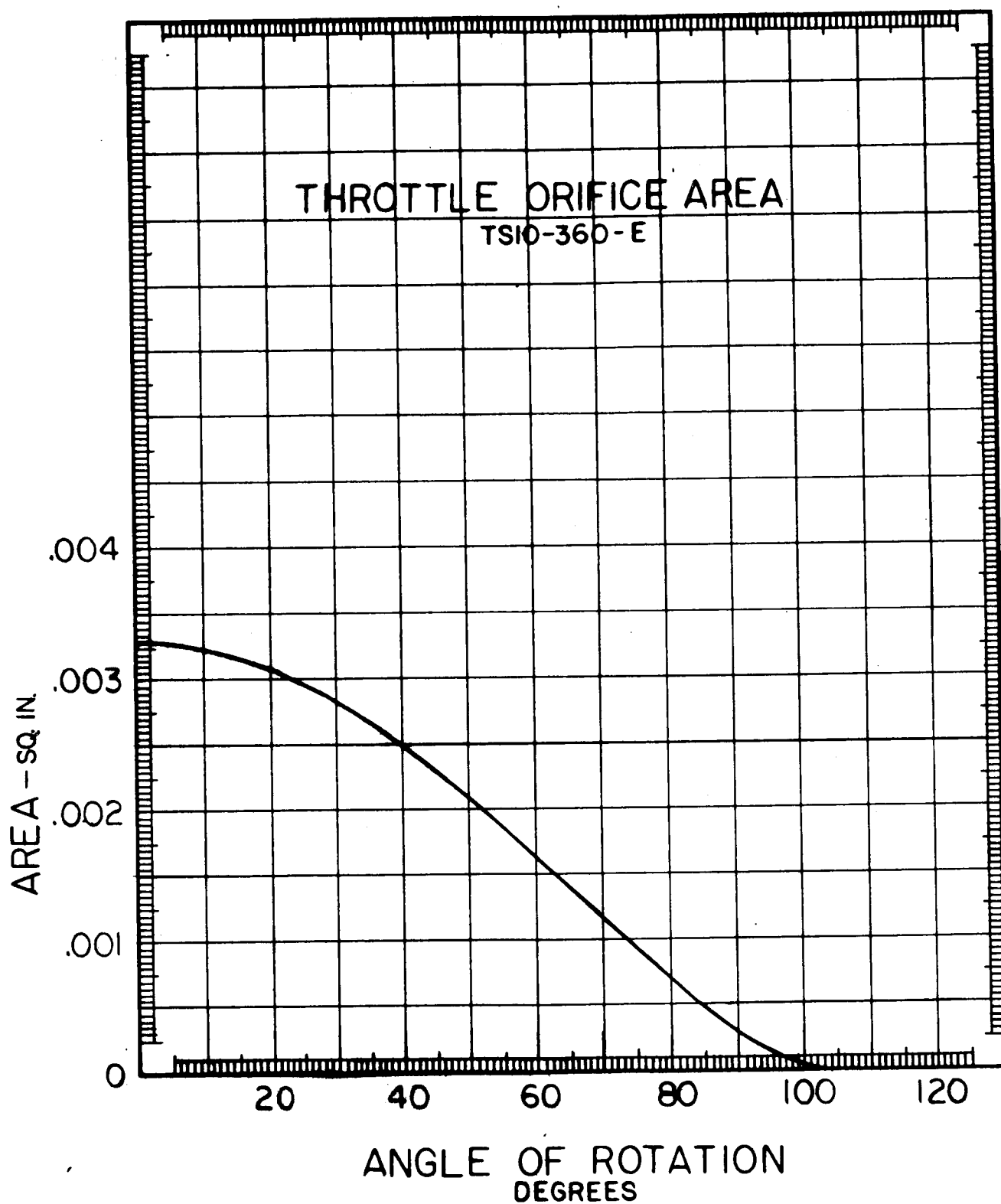
Orifice discharge coefficient is a measure of the flow area to the physical area:

$$\text{Flow area} = C_d * \text{physical area}$$

Figure 26 gives the experimentally determined discharge coefficient for the throttle orifice as a function of orifice physical area.



**FIGURE 23. AIR THROTTLE AND FUEL METERING ASSEMBLY**



**FIGURE 24. THROTTLE ORIFICE AREA**



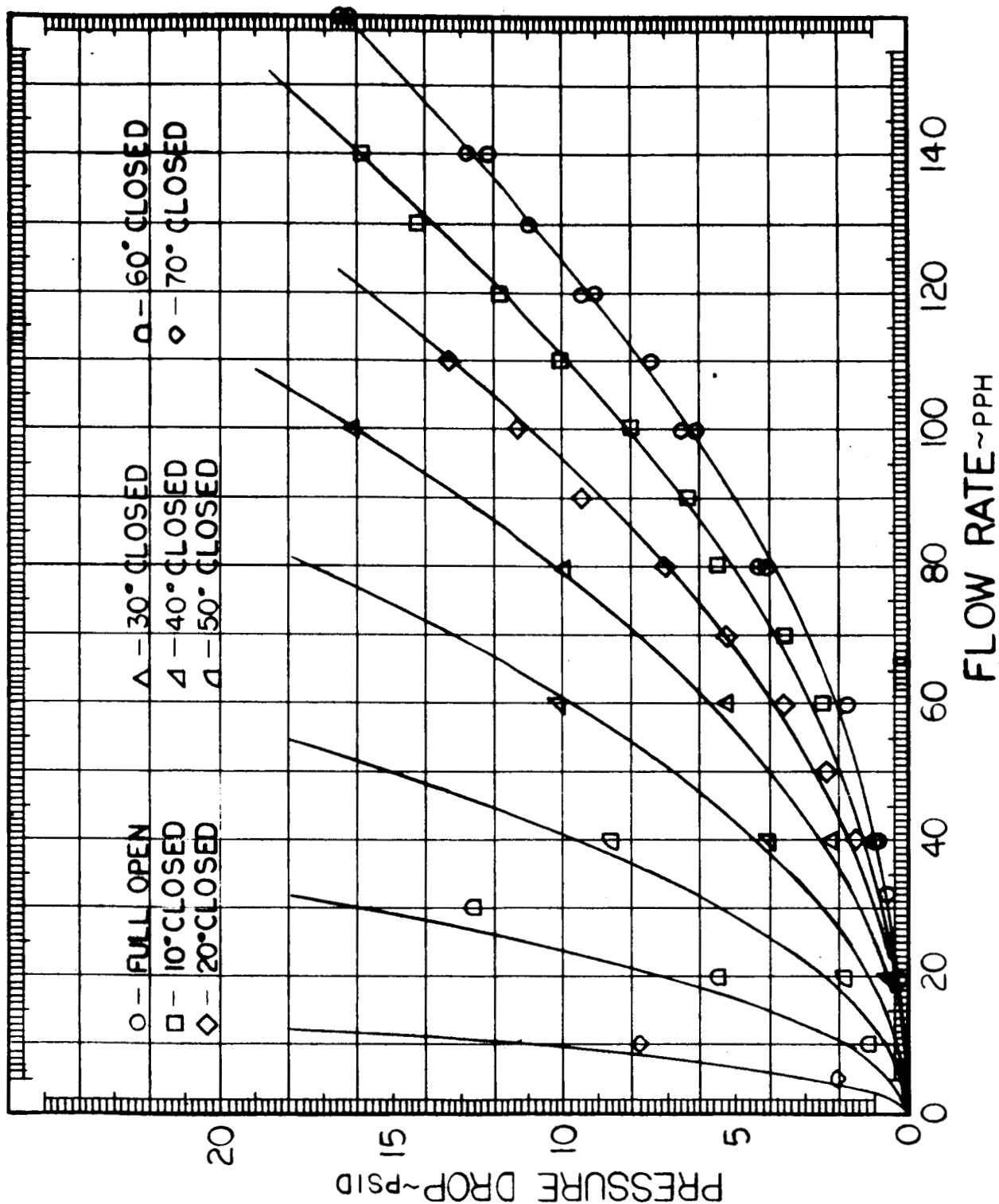


FIGURE 25. THROTTLE ORIFICE PRESSURE LOSS

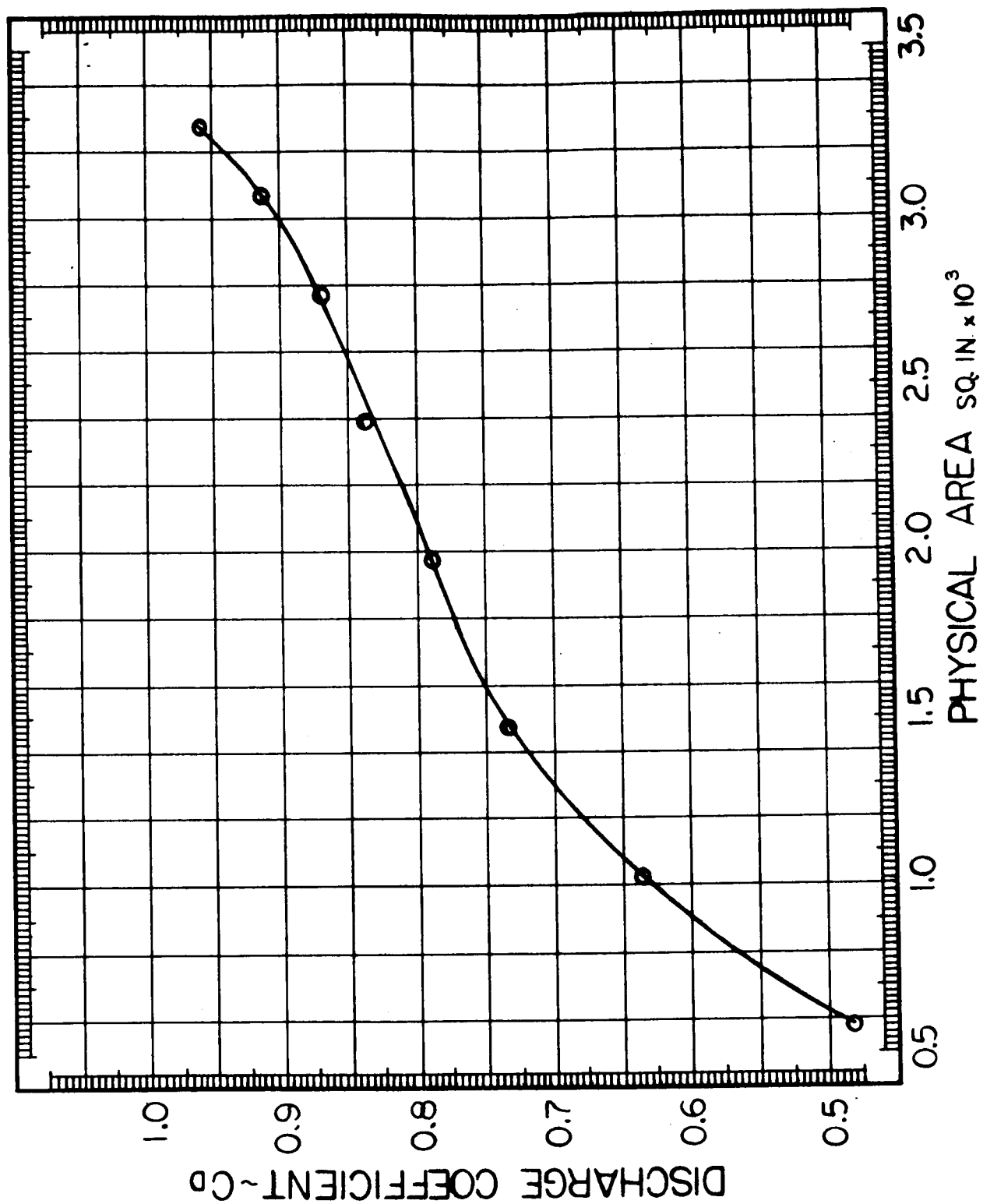


FIGURE 26. THROTTLE ORIFICE DISCHARGE COEFFICIENT

#### 8) Manifold Valve and Nozzles

The manifold valve, nozzle lines and nozzles are factory calibrated as a unit. Figure 27 gives the relationship between fuel flow and metered pressure. Metered fuel pressure is defined as the difference between fuel pressure at the manifold inlet and nozzle reference (turbo discharge) pressure. Fuel flow through the nozzle was found to be independent of manifold pressure. Turbo discharge pressure is fed to the fuel jet as shown in figure 28 and prevents manifold pressure from affecting fuel flow.

#### Simulation Checkout

A number of comparisons between simulation predictions and test data were made to check the computer simulation. Fuel bench tests of the entire fuel system were made to generate data for comparison. When possible, the simulation was compared directly with recorded engine data. However, throttle angle is rarely recorded during engine tests, and the accuracy of the throttle readings are questionable. Bench tests of the complete fuel system were made to simulate engine data by matching engine speed, turbo discharge pressure, and metered fuel pressure as recorded during engine calibration testing (reference 6). Careful measurements of the throttle angle were then made for input to the simulation.

The simulation was first "trimmed," using the variable orifice adjustment corresponding to ground trim on the actual system. Figure 29 shows the manufacturer's recommended flow rate and pressure at high power, as a function of the variable orifice ground trim. The simulation was trimmed to the middle of the recommended bands for fuel flow, metered fuel pressure, and pump discharge pressure. Idle flow rate was trimmed by adjusting the idle relief valve to 7.1 pph at 700 rpm. Fuel pump discharge pressure at idle was 6.7 psig. Continental's spec idle trim is 6 to 8 pph at 700 rpm, with a pump pressure of  $6.5 \pm 0.25$  psig.

After trimming, the simulation predictions were compared to test data. Figure 30 shows the simulation predictions (connected by solid line) compared to fuel bench test data. The engine conditions simulated on the fuel bench correspond to engine prop load conditions, with horsepower ranging from 20 to 100 percent of maximum continuous power. The difference between the predicted and measured flow rate is within the accuracy of the bench measurements. Pump discharge pressure agreed well with measured values.

The effect of turbo discharge pressure on fuel system output is

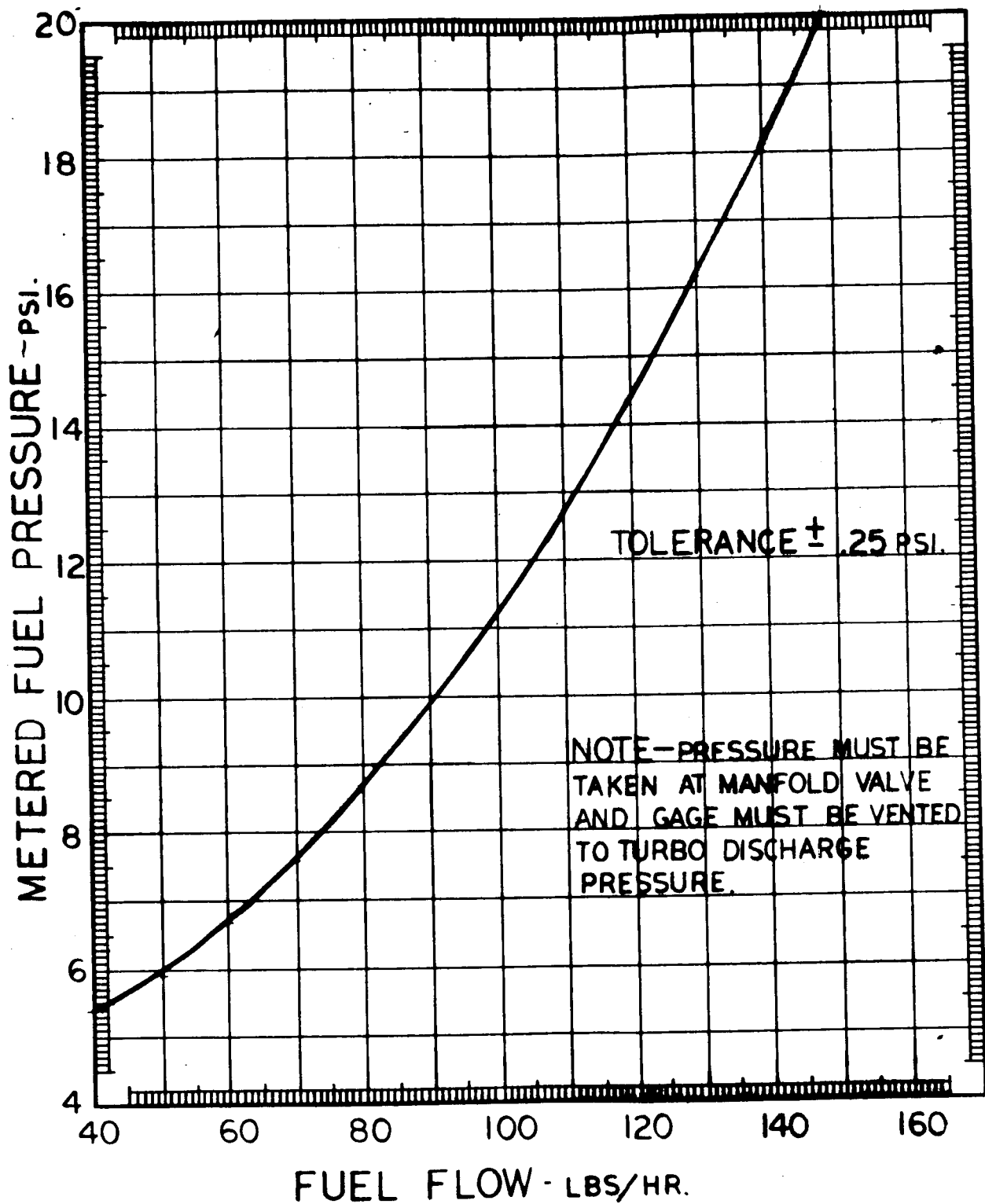
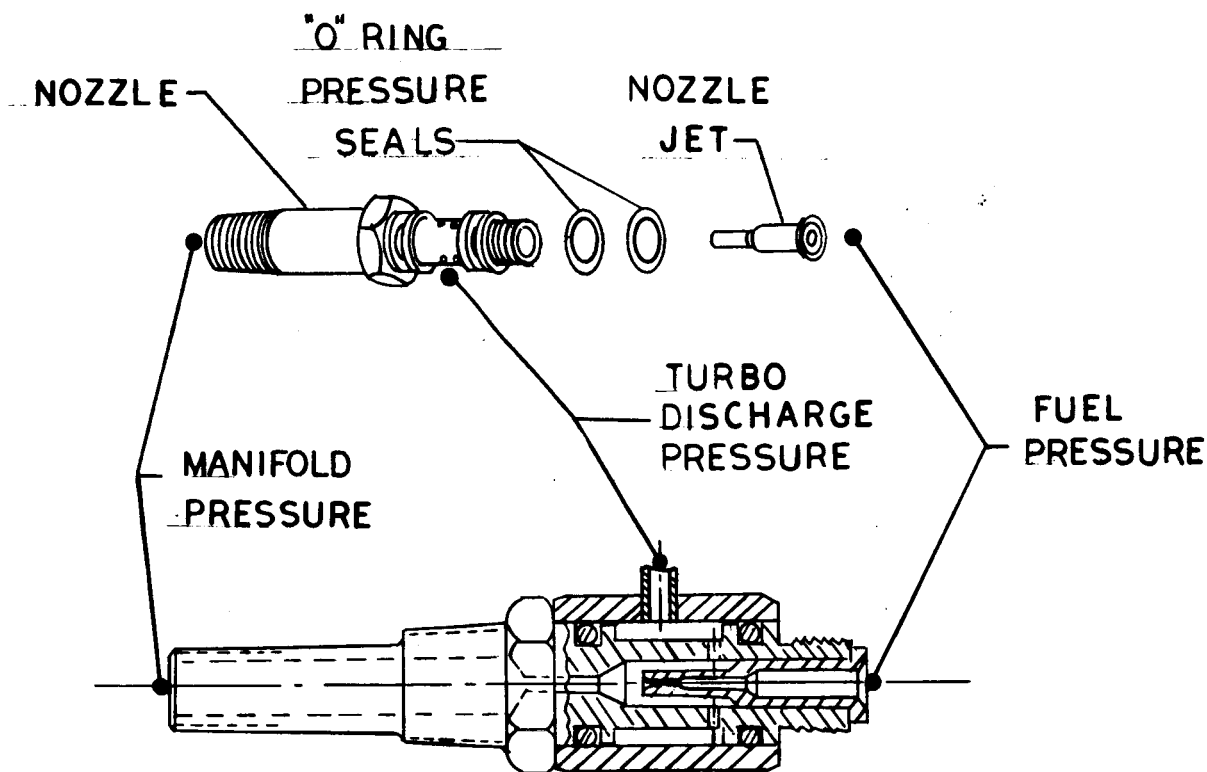
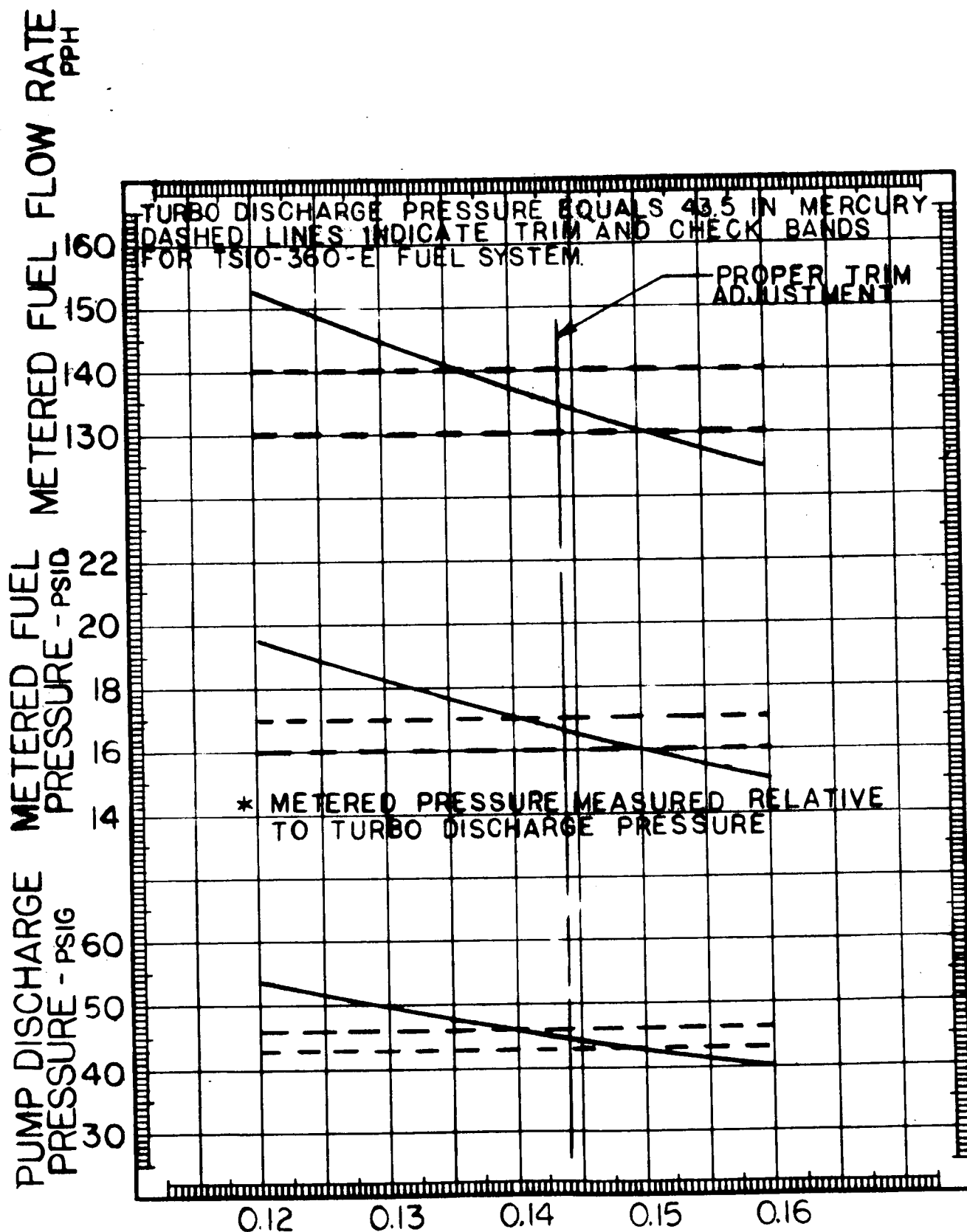


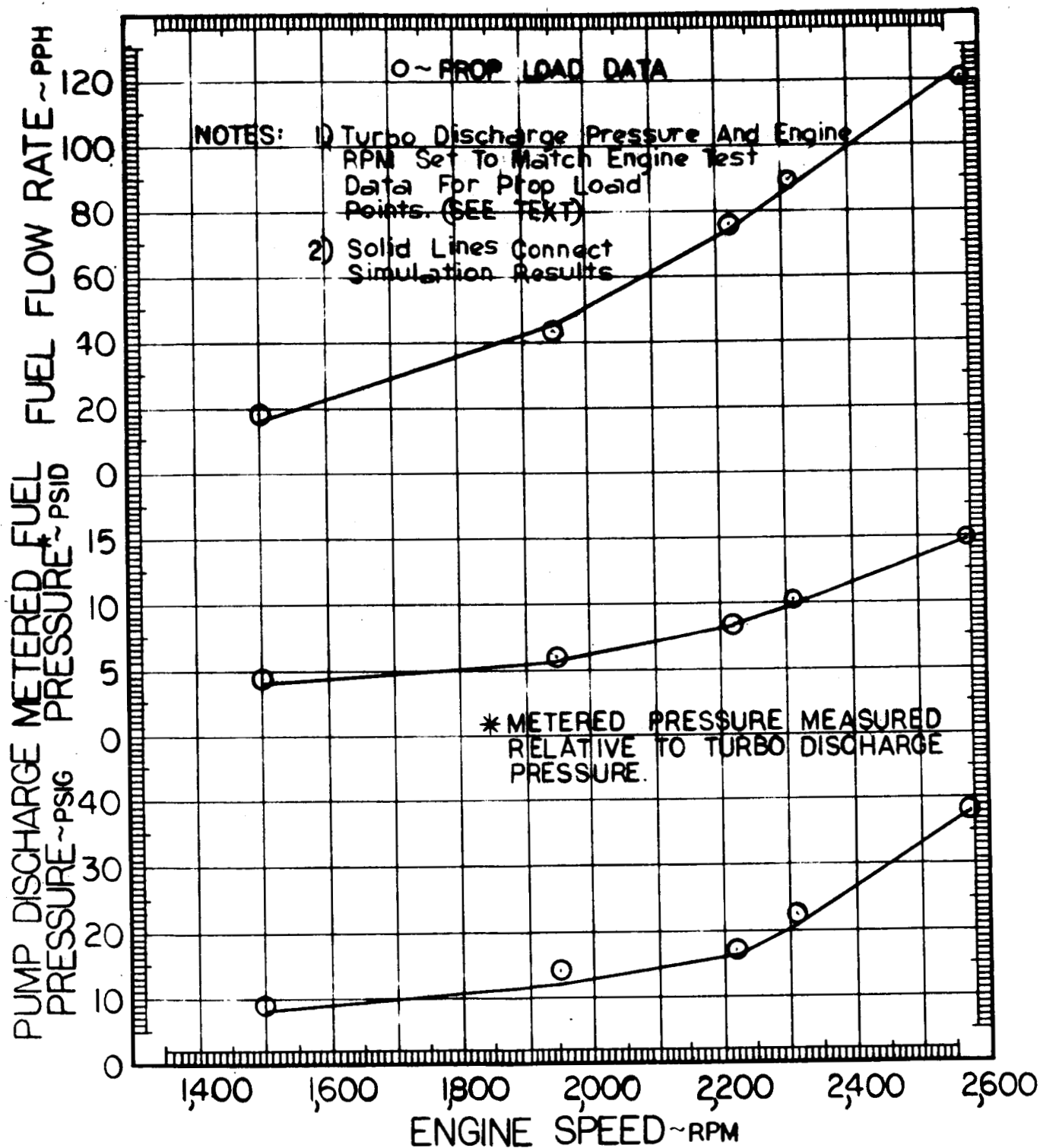
FIGURE 27. METERED FUEL ASSEMBLY CALIBRATION



**FIGURE 28. FUEL NOZZLE DESIGN**



VARIABLE ORIFICE ROD ADJUSTMENT - IN.  
FIGURE 29. SIMULATED HIGH POWER TRIM ADJUSTMENT

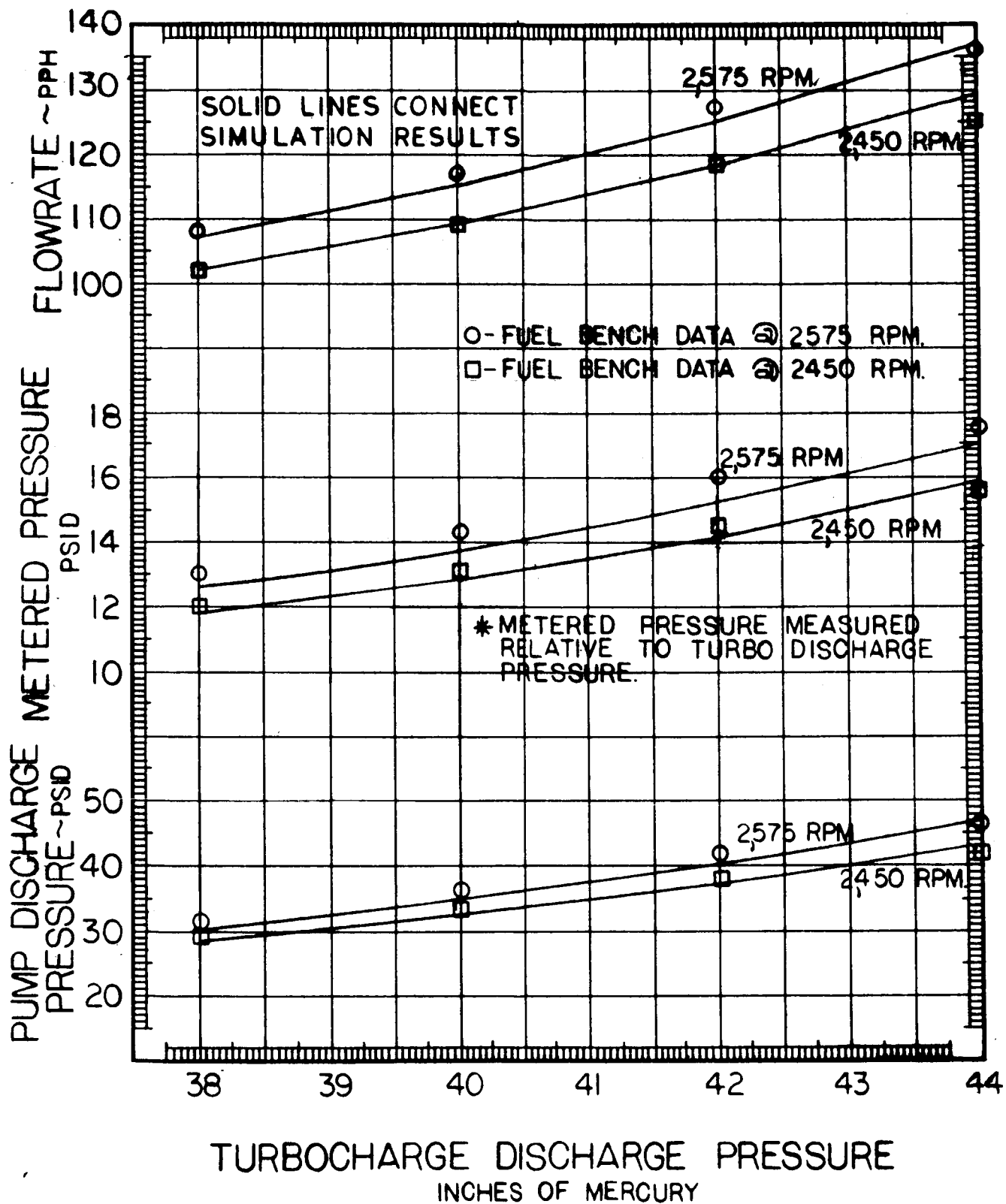


**FIGURE 30. COMPARISON OF FUEL SYSTEM SIMULATION WITH FUEL BENCH TEST DATA**

shown in figure 31 for 2,575 rpm (100 percent power) and 2,450 rpm (75 percent power). Turbo discharge pressure affects the flow rate through the idle relief valve, variable orifice, and nozzles. The comparison shown in figure 31 demonstrates the validity of the simulation of these components.

A direct comparison between the simulation predictions and engine data is shown in figure 32, for constant engine speed and varying manifold pressure. Engine power ranged from 40 to 100 percent of maximum continuous power. Maximum error is less than 10 percent fuel flow at the low power fuel flow. The error for high power was typically less than 3 percent, which is within the measurement tolerance.





**FIGURE 31. COMPARISON OF FUEL SYSTEM SIMULATION WITH FUEL BENCH TEST DATA**

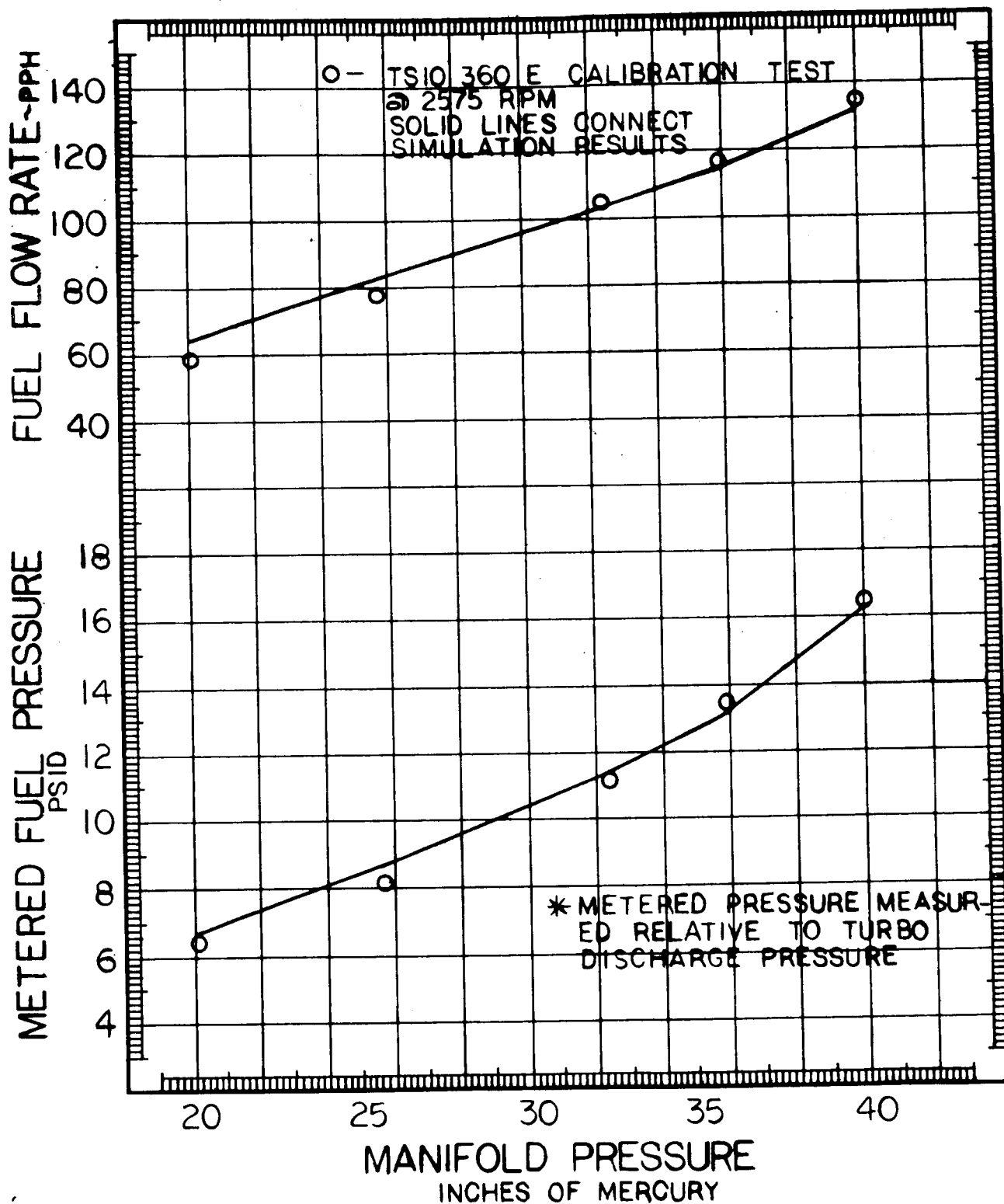


FIGURE 32. COMPARISON OF FUEL SYSTEM SIMULATION  
WITH ENGINE CALIBRATION DATA

## CONCEPTS TO IMPROVE FUEL INJECTION

During phase 1 of the contract, an investigation of the effects of leaning on engine emissions for the NAFEC seven-mode LTO cycle was completed. A review of this study was made to determine the reduction of emissions that could be expected for a TSIO-360-C engine, assuming a means of reducing the engine acceleration lean limit could be found. Table 1 repeats the information for the baseline emissions of the engine reported in reference 1, and shows hydrocarbons to be 212 percent of the proposed standards. Emissions of carbon monoxide and oxides of nitrogen were found to be 193 percent and 9 percent of the proposed standards, respectively. Table 1 also shows the emissions predicted provided the engine acceleration lean limit was reduced to 0.065 fuel/air ratio at low power. These predictions, based on the results found in phase I of the contract, show that the hydrocarbon emissions would be reduced from 212 percent to 48 percent of the proposed EPA standards. Carbon monoxide emissions would be reduced to 140 percent of the EPA standards, and emissions of nitrogen oxides would remain below the EPA standards, increasing to 46 percent. Take-off and climb fuel flows were assumed to be mean values (baseline flows) within the current fuel flow band. These high power conditions are engine temperature limited and the engine must be cooled with sufficient fuel as determined by flight testing a particular installation. The target value of 0.065 fuel/air ratio was picked as a value obtainable by modifying the current Continental fuel system and air intake manifold. Continental engines have demonstrated acceptable acceleration below 0.065 fuel/air ratio with more sophisticated fuel systems and intake manifolds.

Some methods for reducing the engine lean limit for acceleration and improving fuel/air ratio control are given below. The transient response of the turbocharger discharge pressure and flow rate during acceleration must be known in order to tailor the fuel system response to sensed parameters.

### 1) Temperature Compensation

The current fuel system has no means of temperature compensation. This means the fuel system must be adjusted for acceptable engine acceleration at the lowest expected ambient temperature. The effect of ambient temperature on fuel/air ratio for constant fuel flow is shown in figure 33. Given a minimum fuel/air ratio acceleration limit at 0° F, increasing ambient temperature increases the operating fuel/air ratio. Temperature compensation can be added to the Continental system using a N-Propyl Alcohol filled aneroid (figure 34). The aneroid movement necessary to maintain constant fuel/air ratio with varying

TABLE I  
BREAKDOWN OF EMISSIONS BY ENGINE  
OPERATING CONDITION  
TSIO-360-C ENGINE

All Values Are Percent of Proposed EPA Standards

HC EMISSIONS

<u>Operating Condition</u>	(1)		<u>Limit</u>
	<u>Baseline Emissions (%)</u>	<u>Leaned Emissions (%)</u>	
Taxi	154.5	10.5	Accel
Idle	24.0	11.0	Accel
Climb	20.4	20.4	Temp
Approach	11.9	4.9	Accel
Take-off	<u>1.3</u>	<u>1.3</u>	Temp
Total	212.1	48.1	

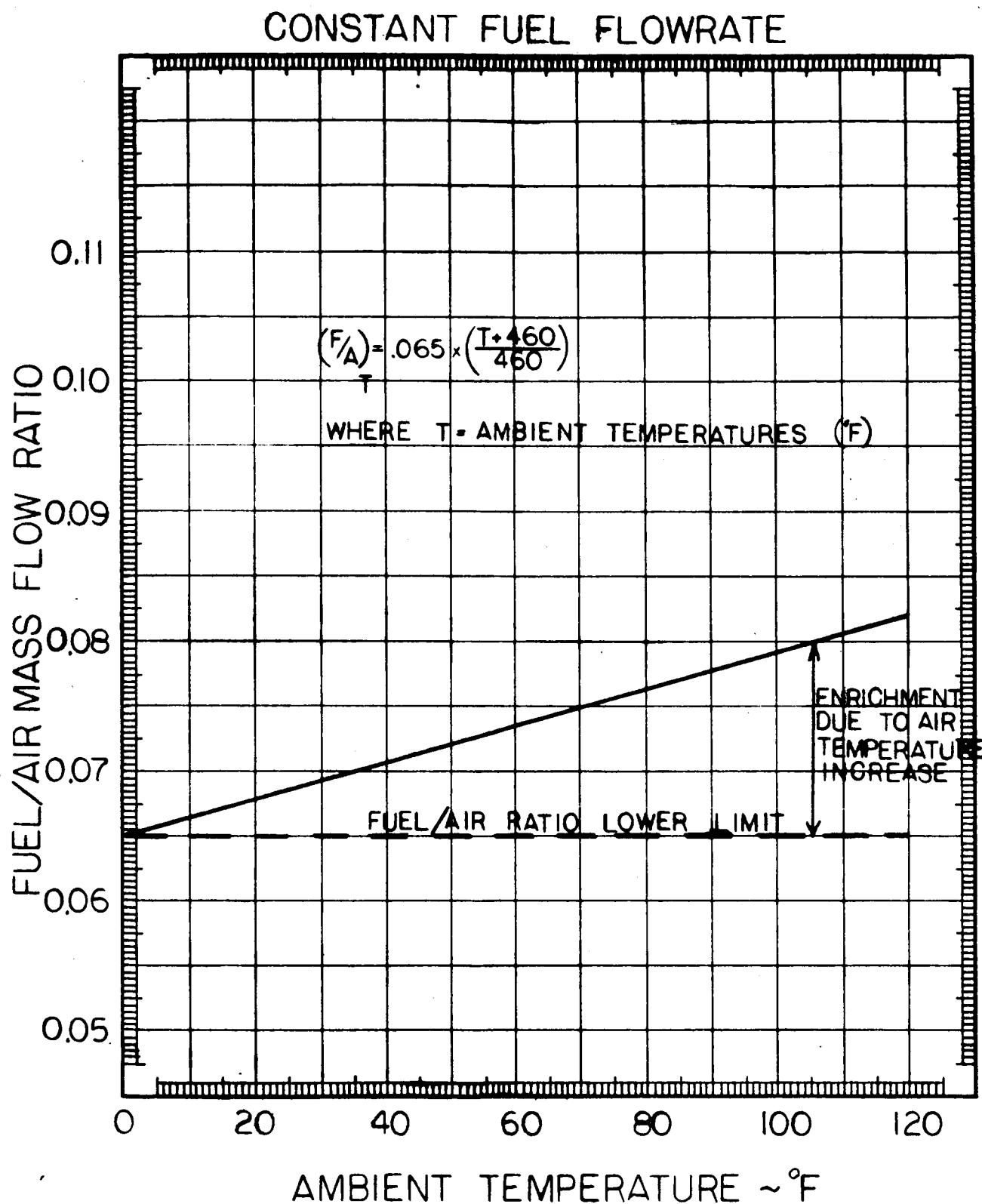
CO EMISSIONS

<u>Operating Condition</u>	(1)		<u>Limit</u>
	<u>Baseline Emissions (%)</u>	<u>Leaned Emissions (%)</u>	
Climb	102.3	102.3	Temp
Approach	54.8	15.9	Accel
Taxi	26.4	12.3	Accel
Take-off	9.5	9.5	Temp
Idle	<u>Neg</u>	<u>Neg</u>	Accel
Total	193.0	140.0	

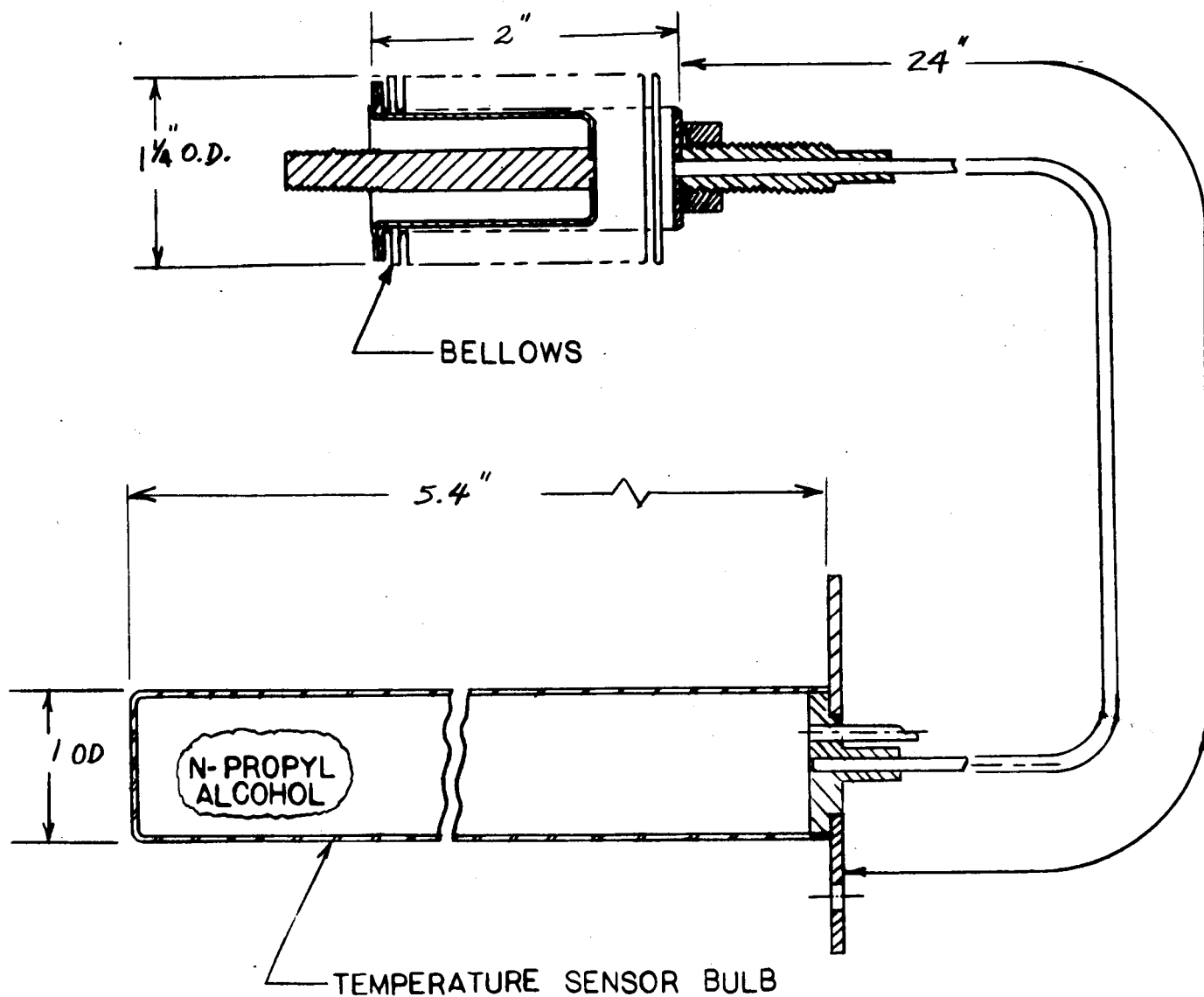
NO EMISSIONS

<u>Operating Condition</u>	(1)		<u>Limit</u>
	<u>Baseline Emissions (%)</u>	<u>Leaned Emissions (%)</u>	
Approach	7.1	38.8	Accel
Climb	0.4	3.3	Temp
Taxi	0.7	1.9	Accel
Idle	0.6	2.0	Accel
Take-off	<u>Neg</u>	<u>Neg</u>	Temp
Total	8.8	46.0	

(1) Acceleration limit assumed to be reduced to 0.065 fuel/air ratio by improving manifold and fuel management.



**FIGURE 33. EFFECT OF AMBIENT AIR TEMPERATURE  
ON ENGINE FUEL /AIR RATIO**



**FIGURE 34. TEMPERATURE SENSING ANEROID DESIGN**

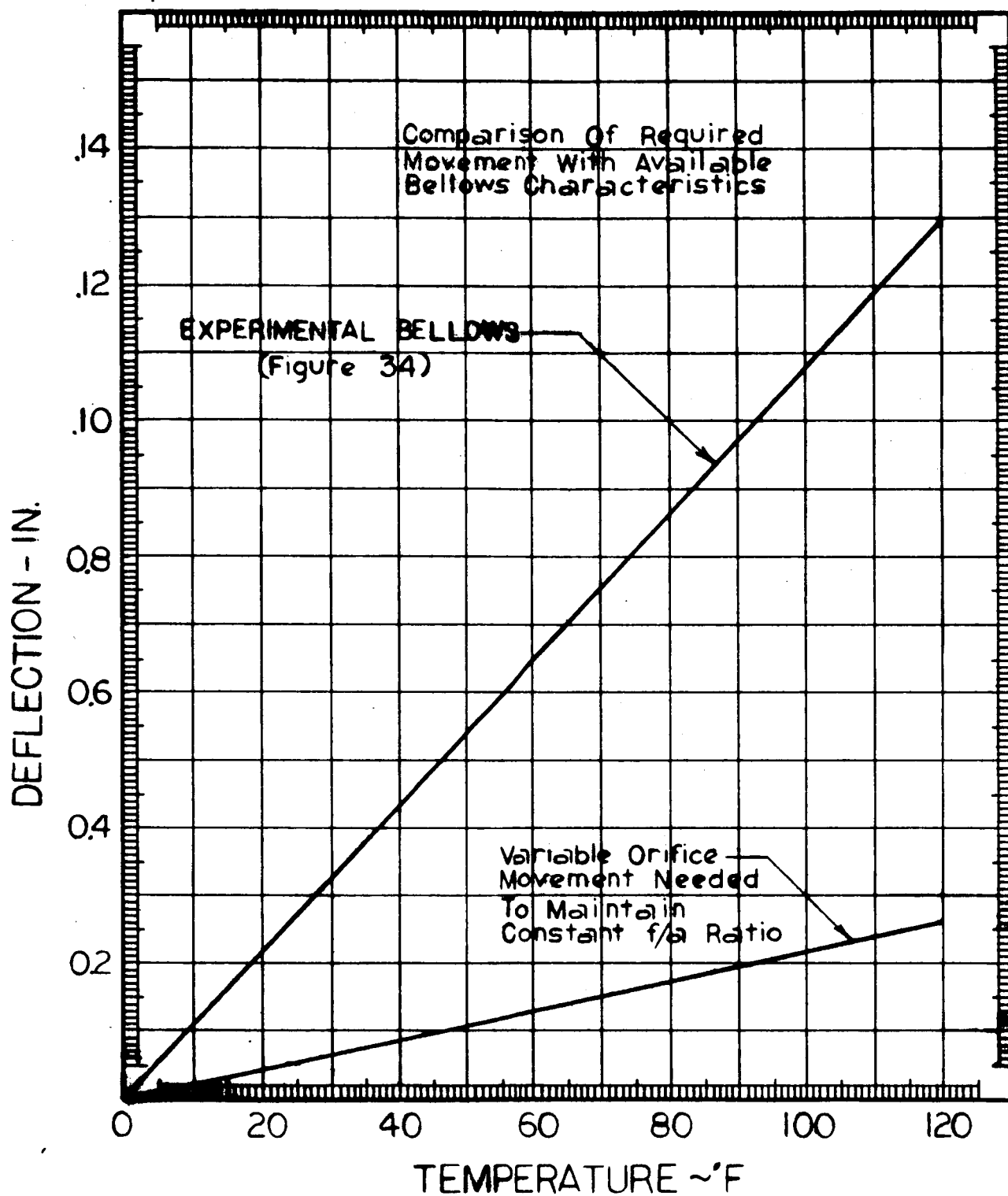


FIGURE 35. BELLOWS MOVEMENT REQUIRED FOR TEMPERATURE COMPENSATION

ambient air temperature is shown in figure 35. This information is based on simulation predictions at taxi (1200 rpm). Also shown is the deflection of an available temperature-sensing aneroid. The sensing bulb volume can be reduced to obtain the desired aneroid response.

2) Improved Nozzle Vaporization

Fuel vaporization is drastically reduced during engine acceleration. During steady state idle or taxi operation, the throttle is nearly closed, giving a pressure difference between turbocharger discharge pressure and manifold pressure. Nozzle vaporization is aided by an air pressure differential of approximately 5 psi. For these conditions, the nozzles emit a fine mist of partially vaporized fuel to the manifold. When the throttle is suddenly opened to accelerate, this nozzle pressure differential vanishes. Fuel is emitted as a steady liquid stream into the manifold, with very little nozzle vaporization.

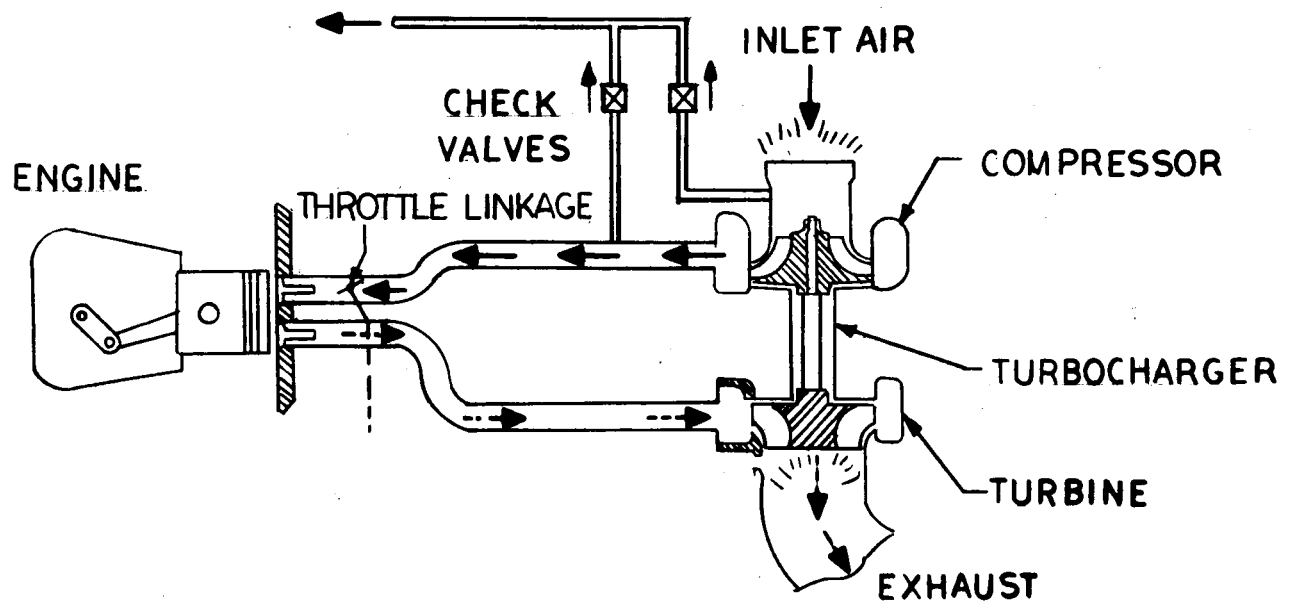
Figure 36 shows a method for improving fuel vaporization during engine acceleration. Acceleration is inhibited by the slow response of the turbocharger, so that the turbocharger compressor acts as a throttle to the engine. The pressure differential across the turbocharger compressor is used by the system shown in figure 36 to improve fuel vaporization during acceleration. The action of the check valves feeds turbocharger inlet pressure to the nozzles when compressor inlet pressure exceeds discharge pressure.

3) Modified Aneroid Response

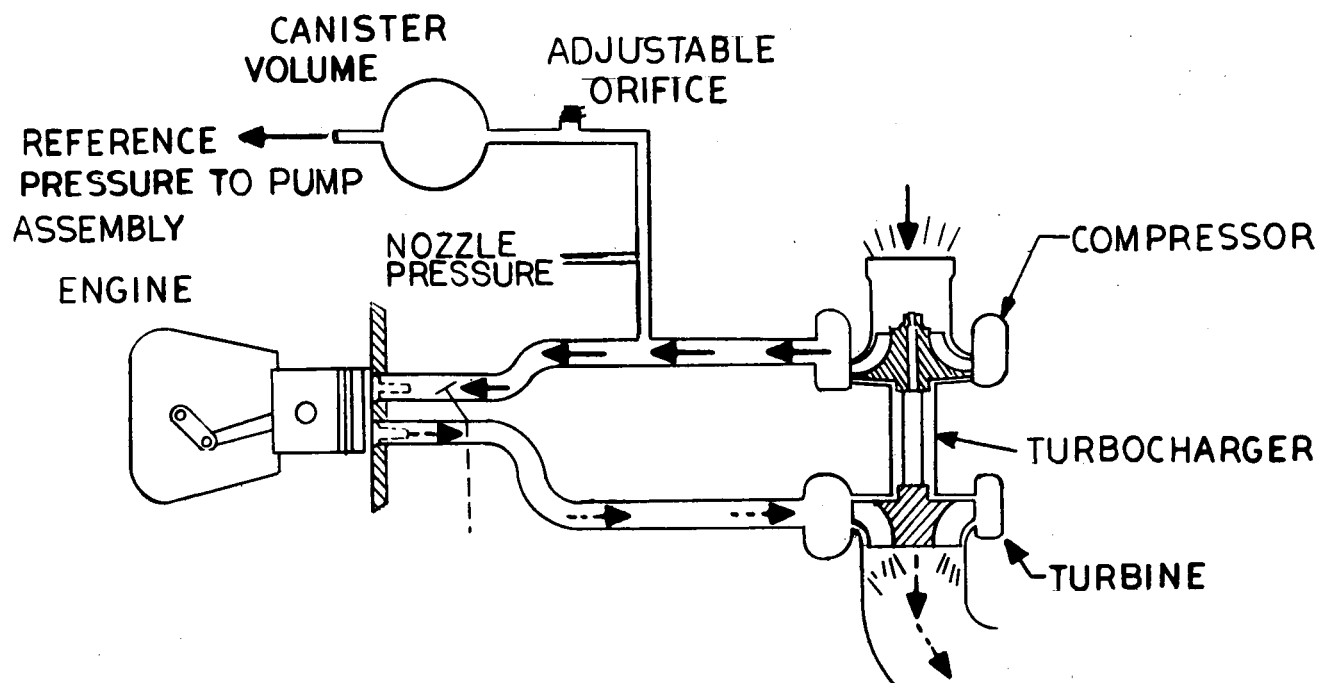
The action of the aneroid during engine acceleration tends to reduce fuel flow as the sensed turbocharger pressure drops from near ambient at steady state conditions with sudden throttle opening. The momentary pressure drop across the compressor which occurs due to slow turbocharger response is sensed by the aneroid. The aneroid expands and opens the variable orifice, reducing fuel system output. This is a desirable action, since the turbocharger is acting essentially like a throttle, reducing engine airflow. However, the response of the aneroid can be adjusted using the system shown in figure 37, for momentary enrichment relative to the current system. This could be used to counter the effects of leaning at steady state conditions, and thus reduce the acceleration lean limit. The probable response of such a system would be as shown qualitatively in figure 38.



REFERENCE PRESSURE  
TO NOZZLES



**FIGURE 36. FUEL SYSTEM MODIFICATION FOR IMPROVED  
FUEL VAPORIZATION DURING ACCELERATION**



**FIGURE 37. FUEL SYSTEM MODIFICATION FOR OFF-IDLE ENRICHMENT DURING ACCELERATION**

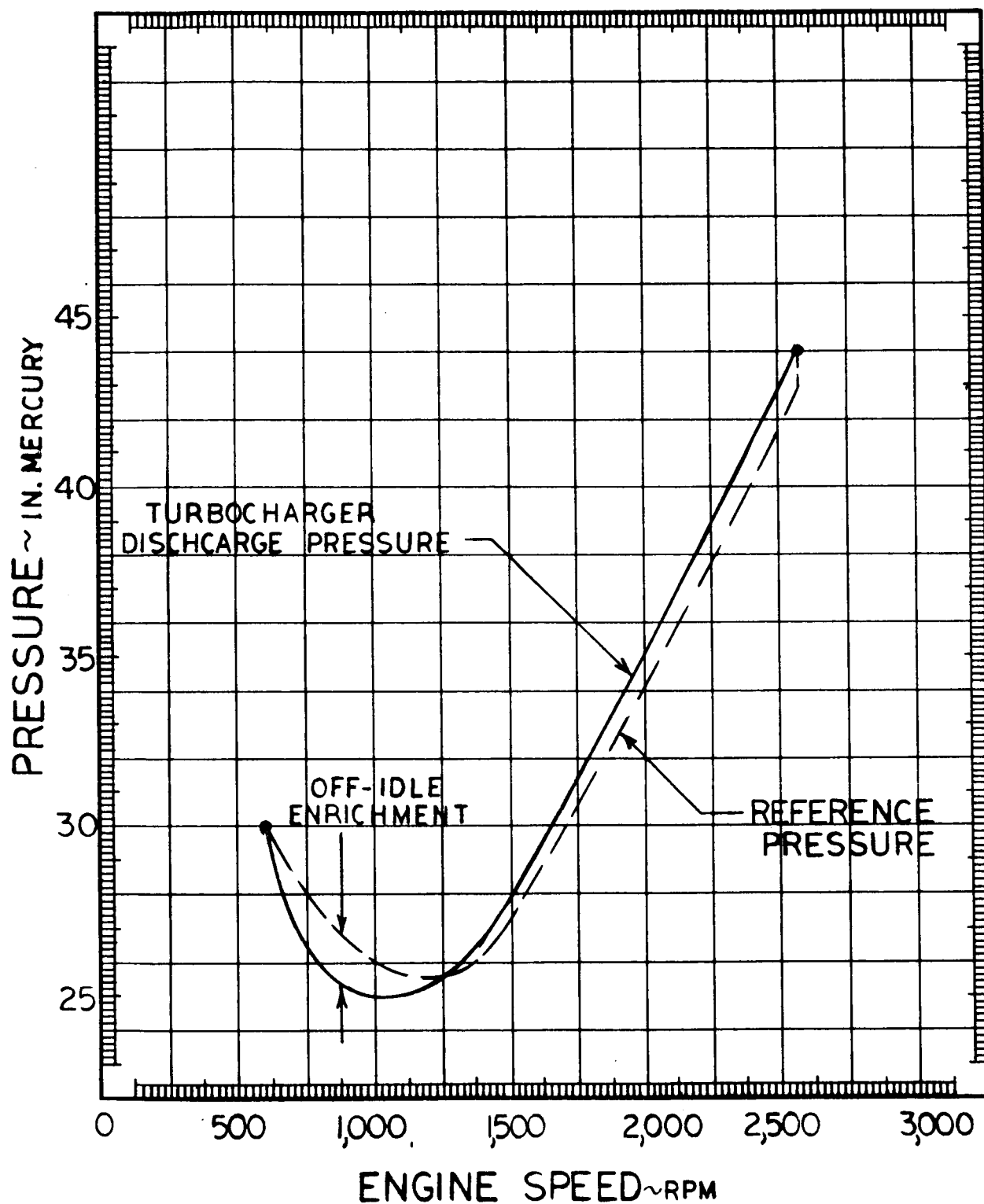


FIGURE 38. DELAYED REFERENCE PRESSURE RESPONSE  
DURING ENGINE ACCELERATION

Although the induced lag of the system initially enriches the mixture, the effect is reversed as the turbocharger compressor pressure begins to increase. Adjustment of the orifice and volume would change the lag of the system, and could be tailored for improved fuel flow during acceleration.

4) Manifold Pressure Compensation

The present fuel injection system senses turbo discharge pressure to adjust the fuel output with changes in air pressure. Turbo discharge pressure can be used, since the fuel system is also linked to the throttle. However, air density and therefore engine airflow are directly proportional to manifold pressure. A more direct method of pressure compensation is to adjust fuel output with manifold pressure. With fuel flow compensation due to manifold pressure and temperature, density compensation could be obtained.

These are just a few of the many possible schemes for improving fuel management. Using the computer model developed for the fuel system and the transient response of the engine as determined from engine test data, the merits of such schemes can be evaluated. However, changes to the fuel injection system alone would not be sufficient to minimize the acceleration lean limit. Engine experience indicates that the manifold system must be modified to improve air distribution to the cylinders. To attain the minimum lean limit for acceleration, the air should be equally distributed to the cylinders at all engine operating conditions.

## CONCLUSIONS

From the results, it is concluded that:

- 1) A computer simulation of the TCM fuel injection system has been developed which predicts accurately the fuel flow for the TSIO-360-E system. Changes in fuel flow due to varying engine conditions, ambient conditions, and fuel system adjustments can be predicted.
- 2) Reduced emissions and improved fuel economy at the full rich setting for cruise power and below can be attained by adding temperature compensation to the fuel system. Temperature compensation would reduce fuel flow for engine operation at high intake temperature.
- 3) Improved fuel management during acceleration along with better airflow distribution would reduce the acceleration lean limit and emissions in the aircraft landing and take-off (LTO) cycle. If modifications are sufficient to reduce the acceleration lean limit to 0.065 fuel/air ratio, hydrocarbon emissions can be reduced to 61 percent of the EPA emission standards for the NAFEC seven-mode LTO cycle. Carbon monoxide emissions would be reduced from 193 percent to 140 percent of the standards. Emissions of nitrogen oxides would remain below the standards at 46 percent.

### REFERENCES

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- 2). Stuckas, Kenneth J., Exhaust Emissions Characteristics of Five Aircraft Piston Engines," Phase I Final Report, NAFEC Contract No. DOT FA74NA-1091, 1977.
- 3). Huebner, Kenneth H., "A Simplified Approach to Flow Network Analysis: Application to Engine Lubrication Systems," SAE Report No. 750080, 1975.
- 4). Crane Engineering Division, "Flow of Fluids Through Valves, Fittings, and Pipe," Crane Technical Paper No. 410 Crane Engineering Co., 4100 S. Kedzie Avenue, Chicago, Ill., 1976.
- 5). "Texaco Aviation Products," Texaco Inc., International Aviation Sales Dept., 135 East 42nd Street, New York, N.Y., 1975.
- 6). Teledyne Continental Motors, "F.A.A. Type Test and Calibration of the Teledyne Continental Model LTSIO-360-E Aircraft Engine," TCM Report No. 640, 1974.

## APPENDIX

### OPERATING INSTRUCTIONS

#### FOR

#### TSIO-360-E FUEL INJECTION SYSTEM COMPUTER SIMULATION

Input to the computer simulation of the Continental TSIO-360-E fuel injection system consists of the engine operating conditions and fuel system adjustments necessary to establish the operating conditions of the system. A complete listing of the input is given in Table A-1. Several computer runs are necessary to establish the input values for valve positions required to simulate a particular fuel system trim. This process is analogous to the actual trimming of the fuel injection system. Two trims are required:

(1) Idle Trim. Computer runs are made simulating idle speed (700 rpm) and throttle position (72° from full open throttle) with several values for idle relief valve adjustment (SAL). These results can be used to determine the approximate relief valve setting required to give the desired idle pump discharge pressure (X2 minus ambient pressure, PAMB). This pressure is generally set to be 6.0 to 6.5 psig. Next, the idle fuel flow adjustment (ADJCU) is varied to establish the correct input to give the desired metered fuel pressure at idle. This pressure is calculated from the computer output for absolute metered fuel pressure (X3, psia) minus turbo discharge pressure (P5, psia), turbo discharge pressure at idle is normally equal to ambient pressure. Idle metered fuel pressure is generally set to be 3.5 to 4.0 psid (referenced to turbo discharge pressure).

(2) Full Power Trim. The simulation is next adjusted at full power (defined as 2575 rpm, 40. inches manifold pressure) using the variable orifice adjustment input. The throttle settings for full power can be determined from actual engine data. Correct full power throttle settings are specified by Continental as a function of density altitude. For engine ground trims, the exhaust waste gate is adjusted to obtain 40 inches of manifold pressure at a specified throttle setting. This full throttle set-

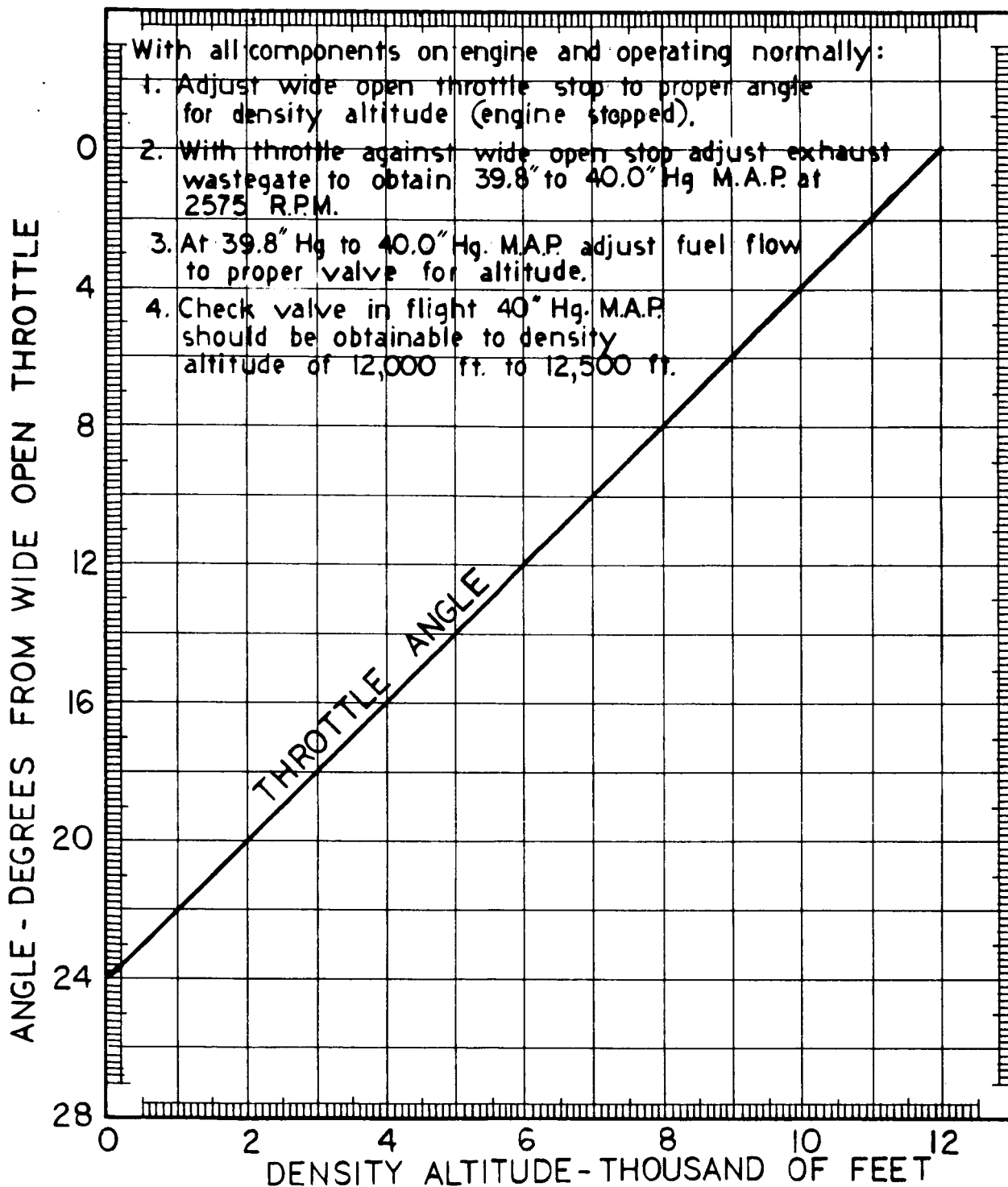
ing is a function of density altitude as specified in figure A-1. Using the full throttle setting (ALFA) as established from engine data or from figure A-1, the variable orifice position (ADJVO) is varied to obtain the desired metered fuel pressure (X3 minus P5) or metered fuel flow (X11). Full power metered fuel pressure is generally set between 16.0 and 17.0 psid (relative to turbo discharge pressure, P5). Corresponding metered fuel flows are 130 to 140 pph. During the trim at idle and full power, aneroid reference pressure (PREF) is set equal to trim full power turbo discharge pressure (approximately 43 to 44 inches of mercury). This pressure should be held constant for subsequent simulations for the same trim setting. Aneroid movement with changes in turbo discharge pressure is referenced to PREF, which may be regarded as a trim parameter.

After trimming the simulation, subsequent simulations can be made varying altitude, engine speed, turbo discharge pressure, throttle angle, or any other input parameter desired to match a given operating condition.

Deck output consists of the results of the iteration process (X1 thru X11) after every 100 completed iteration loops, along with a parameter labeled "B". This parameter is the magnitude of the objective function as described in the discussion section of this report. The iteration continues until the value of the objective function is less than the value input of TOL (Card 2) or until the number of iterations exceeds NMAX. The values of X1 thru X11 corresponding to the sample output are given below, followed by a complete listing of the FORTRAN source program.

Computer Output	Fuel System Parameter	Units	Idle Value	Full Power Value
X1	P1, Pump Inlet Pressure	psia	14.63	10.82
X2	P2, Pump Discharge Pressure	psia	21.40	59.15
X3	P3, Absolute Metered Fuel Pressure	psia	18.59	38.88
X4	P4, Nozzle Pressure	psia	14.79	33.21
X5	P6, Variable Orifice Discharge Pressure	psia	20.96	28.80
X6	P7, Vapor Separator Discharge Pressure	psia	14.77	15.39
X7	Supply Line Flow Rate	pph	26.20	199.6
X8	Pump Flow Rate	pph	149.1	574.8
X9	Vapor Separator Flow Rate	pph	19.05	58.77
X10	Variable Orifice Flow Rate	pph	122.9	375.2
X11	Metered Fuel Flow Rate	pph	7.14	140.8
B	Remainder Term	-	0.00094	0.0085
N	Number of Iterations	-	1891	2500





**FIGURE A-1. INSTRUCTIONS FOR ADJUSTMENT  
OF EXHAUST GAS WASTEGATE**

TABLE A-1

Input to Fuel Injection System Simulation

Card	Column	Symbol	Description	Units	Typical Values	
					Idle	Full Power
1	General Information					
	1-10	TF	Fuel Temperature	°F	80	80
	11-20	PAMB	Ambient Pressure	psia	14.7	14.7
	21-30	PCOWL	Engine Cowl Pressure	psia	14.7	14.7
	31-40	P5	Turbo Discharge Pressure	inches of mercury	43.5	43.5
	41-45*	N	Number of Unknowns (integer)	-	11	11
2	Iteration Parameters					
	1-10	ALPHA	Forward Step Size for Iteration (see text)	-	5.0	5.0
	11-20	TOL	Maximum Value for Remainder Term (see text)	-	0.001	0.001
	21-25*	NMAX	Limit on Maximum Number of Iterations Allowed to Converge	-	2500	2500
3	Initial Guesses for Unknowns					
	1-10	X0(1)	Pump Inlet Pressure (P1)	psia	14.7	10.7
	11-20	X0(2)	Pump Discharge Pressure (P2)	psia	20.7	47.2
	21-30	X0(3)	Absolute Metered Fuel Pressure (P3)	psia	18.2	37.2
	31-40	X0(4)	Nozzle Pressure (P4)	psia	16.0	31.6
	41-50	X0(5)	Variable Orifice Discharge Pressure (P6)	psia	20.0	27.8
	51-60	X0(6)	Vapor Separator Discharge Pressure (P7)	psia	14.7	14.7
	61-70	X0(7)	Supply Line Flow Rate	pph	23.0	181.0

\* Integer Value. Input Right Adjusted in Input Field.

Table A-1 (cont'd)

<u>Card</u>	<u>Column</u>	<u>Symbol</u>	<u>Description</u>	<u>Units</u>	<u>Typical Values</u>	
					<u>Idle</u>	<u>Full Power</u>
4	71-80	XD (8)	Pump Flow Rate	pph	150.	617.
	Initial Guesses for Unknowns (continued)					
	1-10	XD (9)	Vapor Separator Flow Rate	pph	17.0	53.9
	11-20	XD (10)	Variable Orifice Flow Rate	pph	127.	436.
5	21-30	XD (11)	Metered Fuel Flow Rate	pph	6.0	127.
	Supply Line Data					
	1-10	XK	Line K-Factor (Ref3)	-	4.45	4.45
	11-20	DP	Line Diameter	Inch	0.20	0.20
	21-30	XL	Line Length	Inch	180.	180.
	31-40	EPSP	Line Surface Roughness (Ref 3)	Inch	0.000125	0.000125
	41-50	Z0	Line Elevation at Fuel Tank Relative to an Arbitrary Datum	Inch	0.	0.
	51-60	Z1	Line Elevation at Pump Inlet Relative to Same Datum	Inch	0.	0.
	Fuel Pump Data					
	1-10	RPM	Pump Speed (Equals Engine Speed for TSIO-360-E)	rpm	700	2575
6	11-20	DISP	Pump Displacement	cu.inch	0.226	0.226
	21-30	EFF	Pump Efficiency	-	0.9371	0.9371
	Variable Orifice Data					
	1-10	ADJVO	Variable Orifice Adjustment	inch	0.145	0.145
	11-20	PREF	Aneroid Reference Pressure	inches mercury	43.5	43.5
7	21-30	AMS	Slope of Aneroid Movement with Pressure	in/inch mercury	.00925	.00925

Table A-1 (Cont'd)

<u>Card</u>	<u>Column</u>	<u>Symbol</u>	<u>Description</u>	<u>Units</u>	<u>Typical Values</u>	
					<u>Idle</u>	<u>Full Power</u>
	31-40	EROR	Allowable Error in Variable Orifice Iteration Loop. Maximum position error	in	0.01	0.01
8	Relief Valve Data					
	1-10	XK	Idle Relief Valve Spring Constant	lb/in inch	13.7	13.7
	11-20	RD	Pressure Disk Effective Radius	inch	0.326	0.326
	21-30	SAL	Idle Relief Valve Spring Length Adjustment	inch	0.362	0.362
9	Throttle Data					
	1-10	ALFA	Throttle Angle From Full Open Throttle	degrees	72.0	24.0
	11-20	ADJCU	Idle Fuel Flow Adjustment	degrees	5.0	5.0
10	Manifold Valve Data					
	1-10	SALM	Manifold Valve Spring Adjustment (set at factory)	inch	0.2452	0.2452
11	Vapor Return Line Data					
	1-10	XKR	Line K-Factor (Ref3)	-	16.4	16.4
	11-21	DR	Line Diameter	inch	0.20	0.20
	21-30	XLR	Line Length	inch	180.	180.
	31-40	EPSR	Line Surface Roughness (Ref 3)	inch	0.000125	0.000125

Computer Program listing is attached.

```

0001 DIMENSION MS(30,2),D(30),DI(30),EPS(30,30),EPS1(30,30),XI(30),
0002 C X01(30),E(30),X0(30),DENS(50),VISC(50)
0003 COMMON RHO,VISC,PI,PAMB,PCCL,P5
0004 COMMON/AAA/ M1
0005 COMMON/THREE/ XK,DP,XL,Z0,Z1,EPSP
0006 COMMON/FOUR/ DISP,EFF,RPM
0007 COMMON/FIVE/ ADJVO,PREF,AMS,ERUK,AMRF,AMDP,NMAX
0008 COMMON/SIX/ XK,RD,SAL
0009 COMMON/EIGHT/ ALFA,ADJCU
0010 COMMON/XNINE/ SALM
0011 COMMON/ELEVEN/ XKR,DR,XLR,Z0R,Z1K,EPSS
0012 DATA DENS / 1.,1.,5.,0.,-20.,20.,0.,100.,140.,6.47,6.31,6.15,
0013 C 5.99,5.83 /
0014 DATA VIS / 1.,1.,16.,0.,-20.,0.,10.,20.,30.,40.,50.,60.,70.,80.,
0015 C 90.,100.,110.,120.,130.,140.,150.,0.95,0.89,0.84,0.78,0.74,0.70,
0016 C 0.67,0.63,0.60,0.58,0.55,0.52,0.50,0.49,0.48 /
0017 PI=3.14159
0018 BP=0.0
0019 WRITE(3,20)
0020 WRITE(3,15)
0021 15 FORMAT(/ 20X,'**** GENERAL INPUT DATA ****',//)
0022 READ(1,10) TF,PAMB,PCCL,P5,N
0023 10 FORMAT(4F10.5,15)
0024 READ(1,40) ALPHA,TOL,NMAX
0025 40 FORMAT(2F10.5,15)
0026 WRITE(3,21) ALPHA
0027 21 FORMAT(1H1,' FORWARD STEP SIZE FOR ITERATION IS ',F10.4)
0028 WRITE(3,41) TOL,NMAX
0029 41 FORMAT(/, ' ITERATION TOLERANCE FOR THIS RUN IS ',F10.5,/,
0030 C ' MAX NUMBER OF ITERATIONS IS ',15)
0031 BETA=ALPHA/10.
0032 READ(1,11) (X0(I),I=1,N)
0033 C THESE ARE THE INITIAL GUESSES FOR THE UNKNOWNNS
0034 11 FORMAT(8F10.5)
0035 CALL ENGUNB(DENS,1,TF,C,RHU,11)
0036 CALL ENGUNB(VISC,1,TF,0.,VISC,12)
0037 RHO=RHO*7.481
0038 VISC=VISC*1.076E-05/RHC
0039 WRITE(3,12)
0040 12 FORMAT(/ 3X,'FUEL TEMP',10X,'AMB PRESS',10X,'COWL PRESS',10X,
0041 C 'T/C DISCH PRESS',10X,'FUEL DENSITY',10X,'FUEL VISC',/)
0042 WRITE(3,13)
0043 13 FORMAT(5X,'DEG F',14X,'PSIA',15X,'PSIA',15X,'IN. HG. ABS.',13X,
0044 C 'LBM/CU FT',13X,'LBM/(FT*SEC)',/)
0045 WRITE(3,14) TF,PAMB,PCCL,P5,RHU,VISC
0046 14 FORMAT(5X,F5.1,14X,F5.2,14X,F5.2,18X,F5.2,16X,1PE9.3,/)
0047 READ(1,11) XK,DP,XL,EPSP,Z0,Z1
0048 WRITE(3,16)
0049 16 FORMAT(/,20X,'**** INLET LINE INPUT DATA ****',//)
0050 WRITE(3,17) XK,DP,XL,ZC,Z1,EPSP
0051 17 FORMAT(3X,'LINE K-FACTOR = ',F10.5,3X,'LINE DIA = ',F10.2,2X,'IN',
0052 C3X,'LINE LENGTH = ',F10.2,2X,'IN',3X,'TANK FLUID LEVEL = ',F10.2,
0053 C2X,'IN',/, ' PUMP LEVEL = ',F10.2,2X,'IN',3X,'SURF ROUGH = ',F11.4)
0054 READ(1,11) RPM,DISP,EFF

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```

0045      WRITE(3,18)
0046      18 FORMAT(/,20X,'**** PUMP INPUT DATA ****',/)
0047      WRITE(3,19) RPM,DISP,EFF
0048      19 FORMAT(3X,'PUMP SPEED = ',F10.1,3X,'PUMP DISP = ',F10.4,2X,'CU IN',
0049      C,3X,'PUMP VOLUMETRIC EFFICIENCY = ',F10.3)
0049      READ(1,11) ADJVO,PREF,AMS,ERUK
0050      WRITE(3,30)
0051      30 FORMAT(/,20X,'**** VARIABLE ORIFICE INPUT DATA ****',/)
0052      WRITE(3,31) ADJVO,PREF,AMS,ERUK
0053      31 FORMAT(3X,'ADJUSTMENT= ',F10.4,2X,'IN',3X,'REF PRESS= ',F10.2,2X,
0054      C,'IN HG ABS',3X,'ANEROID SLOPE = ',F10.5,2X,'IN/IN HG',
0055      C3X,'ERROR= ',F10.5)
0056      READ(1,11) XK,RD,SAL
0057      WRITE(3,32)
0058      32 FORMAT(/,20X,'**** IDLE RELIEF VALVE INPUT DATA ****',/)
0059      WRITE(3,33) XK,RD,SAL
0060      33 FORMAT(3X,'VALVE SPRING CONSTANT = ',F10.2,2X,'LB-F/IN',3X,'PRESS D
0061      CISK EFFECTIVE RADIUS = ',F10.3,3X,'SPRING ADJUSTED LENGTH = ',
0062      C F10.3,2X,'IN')
0063      READ(1,11) ALFA,ADJCU
0064      WRITE(3,34)
0065      34 FORMAT(/,20X,'**** CONTROL UNIT INPUT DATA ****',/)
0066      WRITE(3,35) ALFA,ADJCU
0067      35 FORMAT(3X,'THROTTLE ANGLE = ',F10.1,2X,'DEG',3X,'IDLE ADJUSTMENT = ',
0068      C F10.1)
0069      READ(1,11) ALFA,ADJCU
0070      WRITE(3,36)
0071      36 FORMAT(/,20X,'**** MANIFOLD VALVE INPUT DATA ****',/)
0072      WRITE(3,37) SALM
0073      37 FORMAT(3X,'ADJUSTED SPRING LENGTH = ',F10.4,2X,'IN')
0074      ZOR=Z0
0075      ZIR=Z1
0076      READ(1,11) XKR,DR,XLR,EPSR
0077      WRITE(3,38)
0078      38 FORMAT(/,20X,'**** RETURN LINE INPUT DATA ****',/)
0079      WRITE(3,39) XKR,DR,XLR,EPSR
0080      39 FORMAT(3X,'LINE K-FACTOR = ',F10.5,3X,'LINE DIA = ',F10.2,2X,'IN',
0081      C 3X,'LINE LENGTH = ',F10.2,2X,'IN',3X,'SURF ROUGH = ',E11.4)
0082      C THE BEGINNING OF ROSENBRACK'S ALGORITHM
0083      C ALPHA=FACTOR BY WHICH LENGTH OF STEP SIZE IS INCREASED.
0084      C BETA=FACTOR BY WHICH LENGTH OF STEP SIZE IS DECREASED.
0085      C E(I)=MAGNITUDE OF INITIAL STEP SIZE.
0086      C THE USER SELECTS VALUES FOR ALPHA AND BETA WHICH LEAD TO RAPID
0087      C CONVERGENCE. TRIAL AND ERROR WITH TWO OR THREE ITERATIONS IS
0088      C USUALLY SUFFICIENT
0089      WRITE(3,20)
0090      20 FORMAT(1H1)
0091      DO 100 NC=1,N
0092
0080
0081
0082

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PAGE 0003

DOS	FORTAN IV	360N-FO-479	3-8	MAINPGM	DATE	01/09/78	TIME	13.24.12	
0083	100	E(NC)=5.						000108	
0084	DO	101 NC=1,N						000109	
0085	XO(	NC)=XO(NC)						000110	
0086	XI(	NC)=XO(NC)						000111	
0087	101	D(	NC)=0.					000112	
0088	DO	119 NC=1,N						000113	
0089	DO	120 NK=1,N						000114	
0090	120	EPS(NC,NK)=0.0						000115	
0091	119	CONTINUE						000116	
0092	M1=	0						000117	
0093	DO	125 NC=1,N						000118	
0094	MS(	NC,1)=0						000119	
0095	125	MS(NC,2)=0						000120	
0096	B=F(	XO)						000121	
0097	NS=	0						000122	
0098	DO	102 NC=1,N						000123	
0099	EPS(	NC,NC)=1.						000124	
0100	WRITE(	3,29)						000125	
0101	29	FORMAT(14H I X0)						000126	
0102	WRITE(	3,26) (1,X0(1),I=1,N)						000127	
0103	26	FORMAT(15,1PE17.6)						000128	
0104	WRITE(	3,23) B						000129	
0105	23	FORMAT(4H B=,E15.6)						000130	
0106	DO	103 NC=1,N						000131	
0107	103	D(	NC)=E(NC)					000132	
0108	104	CONTINUE						000133	
0109	DO	105 I=1,2000						000134	
0110	IF	(NS .GE. 1) GO TO 106						000135	
0111	KK=	I-1						000136	
0112	I=	MOD(KK,N)+1						000137	
0113	M1=	M1+1						000138	
0114	IF(	M1 .GE. NMAX) GO TO 200						000139	
0115	DO	107 NC=1,N						000140	
0116	107	XO(NC)=D(I) *EPS(NC,I) + XI(NC)						000141	
0117	M1=	F(XO)						000142	
0118	IF(	M1.LT.8) GO TO 108						000143	
0119	B=	M1						000144	
0120	DO	109 NC=1,N						000145	
0121	XI(	NC)=XO(NC)						000146	
0122	D(	I)=D(1(I)*D(I)						000147	
0123	D(	I)=ALPHA*D(I)						000148	
0124	MS(	1,1)=MS(1,1)+1						000149	
0125	GO	TO 110						000150	
0126	108	D(1)=-BETA*D(I)						000151	
0127	MS(	1,2)=MS(1,2)+1						000152	
0128	110	NS=10						000153	
0129	DO	111 L=1,N						000154	
0130	N2=	MS(L,1)*MS(L,2)						000155	
0131	111	NS=MIN0(NS,N2)						000156	
0132	105	CONTINUE						000157	
0133	106	CONTINUE						000158	
	C	GET FILE(IN) NEW DIRECTIONS						000159	
0134	DO	112 NC=1,N						000160	
0135	DO	113 NK=1,N						000161	

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D05 FORTRAN IV 360N-FD-479 3-8      MAINPGM      DATE    01/09/78      TIME    13.24.12
0136      113 EPSI(NC,NK)=0.0      000162
0137      112 CONTINUE      000163
0138      DO 114 NC=1,N      000164
0139      114 EPSI(NC,N)=D1(N)*EPS(NC,N)      000165
0140      NI=N-1      000166
0141      123 IF(NI.LT.1) GO TO 124      000167
0142      DO 116 NC=1,N      000168
0143      116 EPSI(NC,NI)=D1(NI)*EPS(NC,NI)+EPSI(NC,NI+1)      000169
0144      NI=NI-1      000170
0145      GO TO 123      000171
0146      124 CONTINUE      000172
0147      DO 300 I=1,N      000173
0148      DO 301 NC=1,N      000174
0149      301 EPS(NC,I)=EPSI(NC,I)      000175
0150      JJ=I-1      000176
0151      DO 400 J=1,JJ      000177
0152      RRI=0.      000178
0153      DO 401 NC=1,N      000179
0154      EPSIP=EPSI(NC,I)*EPS(NC,J)      000180
0155      RRI=RRI+EPSIP      000181
0156      DO 402 NC=1,N      000182
0157      402 EPS(NC,I)=EPS(NC,I)-RRI*EPS(NC,J)      000183
0158      400 CONTINUE      000184
0159      RR=0.      000185
0160      DO 302 NC=1,N      000186
0161      EPSIP=EPS(NC,I)*EPS(NC,I)      000187
0162      302 RR=RR+EPSIP      000188
0163      RR=RR/RR      000189
0164      DO 303 NC=1,N      000190
0165      303 EPS(NC,I)=EPS(NC,I)/RR      000191
0166      300 CONTINUE      000192
0167      DO 117 NC=1,N      000193
0168      X01(NC)=X1(NC)      000194
0169      117 O1(NC)=0.      000195
0170      DO 118 NC=1,N      000196
0171      MS(NC,1)=0      000197
0172      118 MS(NC,2)=0      000198
0173      NS=0      000199
      C THE FOLLOWING STATEMENT IS AN ERROR CRITERION THAT CAN BE USER
      C ADJUSTED. B IS THE LATEST VALUE OF THE OBJECTIVE FUNCTION AND
      C THIS VALUE MUST BE LOWER THAN SOME SPECIFIED CCNSTANT
      C (TOL) BEFORE THE SEARCH PROCEDURE STOPS
      IF(ABS(B) .LT. TOL) GO TO 200
      C M1 IS THE NUMBER OF FUNCTION EVALUATIONS THAT HAVE OCCURRED DURING
      C THE SEARCH FOR THE MINIMUM VALUE OF THE OBJECTIVE FUNCTION. IF M1
      C BECOMES TOO LARGE (GE NMAX), THE SEARCH PROCEDURE STOPS
      IF(M1 .GE. NMAX) GO TO 200
      KJ=MOD(M1,100)
      IF(KJ .NE. 0) GO TO 104
      IF(BP .EQ. 0) GO TO 104
      RED=ABS((BP-B)/BP)
      IF(RED.LT. .05) GO TO 200
      BP=B
      GO TO 104
0174
0175
0176
0177
0178
0179
0180
0181
0182

```



13.24.12

TIME

DATE 01/09/78

MAINPGM

3-8

DOS FORTRAN IV 360N-ED-479

```

0183 C THIS IS THE MAIN ITERATION LCOP RETURN PATH
0184 C ROSENKRUCH'S ALGORITHM ENDS HERE
0185 200 WRITE(3,25) M1
0186 25 FORMAT(37H NUMBER OF ITERATIONS REQUIRED EQUALS,15)
0187 WRITE(3,28) I XI)
0188 28 FORMAT(14H I XI)
0189 WRITE(3,26) (I,XI(I),I=1,N)
0190 27 FORMAT(5H B= ,E15.6)
0191 WRITE(3,42) AMRF,AMDP
0192 42 FORMAT(1,1 ANEROID MOVEMENT DUE TO ROD FORCE EQUALS ,F10.5,
0193 C/,1 ANEROID MOVEMENT DUE TO T/C DISCHARGE PRESSURE EQUALS ,
C F10.5)
0192 CALL EXIT
0193 END
000216
000217
000218
000219
000220
000221
000222
000223
000224
000225
000226
000227
000228
000229
000230

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DOS FORTRAN IV 360N-FO-479 3-8      MAINPGM      DATE 01/09/78      TIME 13.24.42
C THE FOLLOWING FUNCTION PROCEDURE DEFINES THE OBJECTIVE FUNCTION.
C EQUATION 15 FROM HUEBNER'S TEXT
0001 FUNCTION F(X)
0002 DIMENSION X(30)
0003 COMMON/AAA/ M1
0004
0005 T=F1(X(7),X(9),X(11))*2 + F2(X(7),X(8),X(10))*2
0006 C + F3(X(1),X(7))*2 + F4(X(1),X(2),X(4))*2
0007 C + F5(X(2),X(5),X(10))*2 + F6(X(1),X(5))*2
0008 C + F7(X(2),X(6),X(9))*2 + F8(X(2),X(3),X(11))*2
0009 C + F9(X(3),X(4),X(11))*2 + F10(X(4),X(11))*2
0010 C + F11(X(6),X(9))*2
0011 F=-T
0012 J=MOD(M1,100)
0013 IF(J.NE.0) GO TO 513
0014 WRITE(3,512) F,M1
0015 512 FORMAT(9H F EQUALS,F17.6,10H M1 EQUALS,I5)
0016 WRITE(3,28)
0017 28 FORMAT(14H I
0018 WRITE(3,26) (I,X(I),I=1,11)
0019 26 FORMAT(15,1PE17.6)
0020 513 CONTINUE
0021 RETURN
0022 END
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13.25.01

TIME

DATE 01/09/78

MAINPGM

DOS FORTRAN IV 360N-FO-479 3-8

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0001 C LISTING OF FUNCTION PROCEDURES FOR THE NETWORK. EACH FUNCTION
0002 C REPRESENTS EITHER THE PRESSURE-FLOW RELATION FOR A FLOW PATH OR
0003 C AN EXPRESSION OF FLOW CONTINUITY AT SOME NODES.
0004 C FOR THE LTS10-360E FUEL INJECTION SIMULATION I DEFINED
0005 C
0006 C X(1)=P1
0007 C X(2)=P2
0008 C X(3)=P3
0009 C X(4)=P4
0010 C X(5)=P6
0011 C X(6)=P7
0012 C X(7)=WA
0013 C X(8)=WB
0014 C X(9)=WC
0015 C X(10)=WD
0016 C X(11)=WE
0017 C FUNCTION F1(X7,X9,X11)
0018 C CONTINUITY AT JUNCTION 0
0019 C COMMON/AAA/ M1
0020 C F1= X7-X11-X9
0021 C JJJ=MOD(M1,100)
0022 C IF(JJJ.NE.0) GO TO 1000
0023 C WRITE(3,1100) F1
0024 C 1100 FORMAT( E13.4)
0025 C 1000 CONTINUE
0026 C RETURN
0027 C END
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DOS FORTRAN IV 360N-EO-475 3-8

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0001      FUNCTION F2(X7,X8,X1C)
0002      C
0003      CONTINUITY AT JUNCTION 1
0004      COMMON/AAA/ M1
0005      F2= X8-X7-X1C
0006      JJJ=MOD(M1,100)
0007      IF(JJJ.NE.0) GO TO 1000
0008      WRITE(3,1100) F2
0009      1100 FORMAT( E13.4)
0010      1000 CONTINUE
0011      RETURN
0012      END
0013
0014      000280
0015      000281
0016      000282
0017      000283
0018      000284
0019      000285
0020      000286
0021      000287
0022      000288
0023      000289
0024      000290
    
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0001      FUNCTION F3(X1,X7)
0002      C      PRESSURE LOSS THROUGH THE SUPPLY LINE
0003      DIMENSION FRIL(217),FRI2( 56),FRIC(273)
0004      COMMON RHO,VISC,PI,PAMB,PCCL,P5
0005      COMMON/AAA/ M1
0006      COMMON/THREE/XK0,D,XL,Z0,Z1,EPS
0007      EQUIVALENCE (FRIC(1),FRI1(1)),(FRIC(218),FRI2(1))
0008      DATA FRIL / 1.,1.,17.,14.,1.E-06,1.E-05,5.E-05,1.E-04,2.E-04,
0009      C4.E-04,6.E-04,8.E-04,1.E-03,2.E-03,6.E-03,8.E-03,1.E-02,
0010      C1.E-02,2.E-02,3.E-02,3.E+03,5.E+03,8.E+03,1.5E+04,3.E+04,6.E+04,
0011      C1.E+05,2.E+05,4.E+05,8.E+05,2.E+06,4.E+06,1.E+07,0.044,0.037,
0012      C.032,0.0275,0.023,0.0198,0.0178,0.0155,0.0136,0.012,0.0102,0.0092,0.0083,
0013      C.0081,0.044,0.037,0.032,0.0275,0.023,0.0198,0.0178,0.0155,0.0138,0.0122,
0014      C.0108,0.0098,0.0092,0.0089,0.044,0.037,0.032,0.0275,0.023,0.0198,0.018,0.016,
0015      C.0142,0.013,0.0118,0.0112,0.0105,0.0108,0.044,0.037,0.032,0.0275,0.023,
0016      C.0202,0.0184,0.0164,0.0145,0.0137,0.0128,0.0122,0.0120,0.044,0.037,
0017      C.032,0.0275,0.024,0.0208,0.0190,0.0170,0.0158,0.0149,0.0141,0.0139,0.0138,
0018      C.0138,0.044,0.037,0.032,0.0275,0.0245,0.0217,0.020,0.0182,0.0172,0.0167,
0019      C.016,0.016,0.016,0.044,0.037,0.032,0.0275,0.025,0.0222,0.0208,0.0192,
0020      C.0183,0.0180,0.0175,0.0175,0.0175,0.0175,0.044,0.0375,0.033,0.029,0.0252,
0021      C.023,0.0215,0.0202,0.0195,0.019,0.0189,0.0188,0.0188,0.044,0.038,
0022      C.034,0.0295,0.0258,0.0235,0.0222,0.021,0.0202,0.02,0.02,0.02,0.045,
0023      C.039,0.0355,0.031,0.028,0.026,0.025,0.0242,0.024,0.0237,0.0237,0.0237,0.0237,
0024      C.0237,0.047,0.0415,0.038,0.034,0.0315,0.03,0.0295,0.029,0.029,0.029,
0025      C.029,0.029,0.029,0.0485,0.0435,0.04,0.0365,0.0348,0.0335,0.033,0.0325,0.032,
0026      C.032,0.032,0.032,0.032,0.0495,0.045,0.042,0.0395,0.0375,0.036,0.0358,
0027      C.0355,0.0355,0.0355,0.0355,0.0355,0.0355 /
0028      DATA FRIL / .052,0.047,0.044,0.0415,0.040,0.039,0.0382,0.038,0.038,0.038,
0029      C.038,0.038,0.038,0.055,0.0515,0.049,0.0462,0.045,0.044,0.044,0.044,
0030      C.044,0.044,0.044,0.044,0.044,0.044,0.044,0.044,0.044,0.044,0.044,0.044,
0031      C.049,0.049,0.049,0.049,0.049,0.049,0.049,0.049,0.049,0.049,0.049,0.049,
0032      C.0575,0.0575,0.0575,0.0575,0.0575,0.0575,0.0575,0.0575,0.0575,0.0575,0.0575,0.0575,
0033      C FLOW IN PPH,DIA IN INCHES,ABS. VLS IN LBM/(FT*SEC),EPS IN INCHES
0034      W=X7
0035      A=PI*(D**2)/4.
0036      REY=(W*D/(A*VISC))*(12./3600.)
0037      REY=ABS(REY)
0038      EOD=EPS/D
0039      CALL ENGUNB(FRIC,1,EOD,REY,FF,IE)
0040      IF(REY.LT.3000) FF =64./REY+.001
0041      Q=0.5*W*ABS(W)*144./((3600.)*2/RHO/(A**2)/32.2
0042      XK=XK0+FF*XL/D
0043      DP=XK*Q
0044      DP=DP+ RHO*(Z1-Z0)/1728.
0045      F3= PAMB-X1-DP
0046      JJJ=MOD(M1,100)
0047      IF(JJJ.NE.0) GO TO 1000
0048      WRITE(3,1100) REY,FF,Q,DP,F3
0049      1100 FORMAT( 5E13.4)
0050      1000 CONTINUE
0051      RETURN
0052      END

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0001      FUNCTION F4(X1,X2,X8)
0002      C      PRESSURE RISE THROUGH VANE PUMP
0003      C      EFFICIENCY BASED ON RHO OF 45.41
0004      C      COMMON RHO,VISC,PI,PAMB,PCCL,P5
0005      C      COMMON/AAA/ M1
0006      C      COMMON/FOUR/ DISP,EFF,RPM
0007      C      DIMENSION PUMP(100)
0008      C      DATA PUMP /1.,1.,17.,0.,0.,75.,111.,145.,175.,203.,5.227.,249.,
0009      C      268.,285.,302.,318.,334.,364.,394.,424.,454.,0.,5.,10.,15.,
0010      C      20.,25.,30.,35.,40.,45.,50.,55.,60.,70.,80.,90.,100./
0011      C      RHO=45.41
0012      C      W=X8
0013      C      ACTUAL FLOW IS NOW CONVERTED TO MEASURED FLOW
0014      C      W=W/1.02
0015      C      WLEAK=(RHO*DISP/1728.*RPM*60.*EFF - W)*SQRT(RHOT/RHO)
0016      C      IF(WLEAK.LT.0.) WLEAK=C.
0017      C      CALL ENGUNB(PUMP,1,WLEAK,0.,DP,IE)
0018      C      F4=(X2-X1)-DP
0019      C      JJJ=MOD(M1,100)
0020      C      IF(JJJ.NE.0) GO TO 10CC
0021      C      WRITE(3,1100) WLEAK,DP,F4
0022      C      1100 FORMAT(3E13.4)
0023      C      1000 CONTINUE
0024      C      RETURN
0025      C      END

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DOS FORTRAN IV 360N-FO-479 3-8      F5      DATE 01/09/78      TIME 13.26.00
0001      FUNCTION F5(X2,X5,X10)      000368
0002      PRESSURE DROP THROUGH VARIABLE ORIFICE      000369
0003      COMMON RHO,VISC,PI,PAMB,PCWL,P5      000370
0004      COMMON/AAA/ M1      000371
0005      COMMON/FIVE/ ADJVO,PREF,AMS,EROK,AMRF,AMDP,NMAX      000372
0006      DIMENSION AKFCT(100)      000373
0007      DATA AKFCT / 1.,1.,16.,6.,0.,0.001,0.002,0.003,0.004,0.005,0.006,      000374
0008      CO.007,0.008,0.0087,0.009,0.010,0.012,0.014,0.016,0.018,0.020,0.022,      000375
0009      CO.024,0.026,0.028,0.030,0.032,0.034,0.036,0.038,0.040,0.042,0.044,      000376
0010      CO.046,0.048,0.050,0.052,0.054,0.056,0.058,0.060,0.062,0.064,0.066,      000377
0011      CO.068,0.070,0.072,0.074,0.076,0.078,0.080,0.082,0.084,0.086,0.088,      000378
0012      CO.090,0.092,0.094,0.096,0.098,0.100,0.102,0.104,0.106,0.108,0.110,      000379
0013      CO.112,0.114,0.116,0.118,0.120,0.122,0.124,0.126,0.128,0.130,0.132,      000380
0014      CO.134,0.136,0.138,0.140,0.142,0.144,0.146,0.148,0.150,0.152,0.154,      000381
0015      CO.156,0.158,0.160,0.162,0.164,0.166,0.168,0.170,0.172,0.174,0.176,      000382
0016      CO.178,0.180,0.182,0.184,0.186,0.188,0.190,0.192,0.194,0.196,0.198,      000383
0017      CO.200,0.202,0.204,0.206,0.208,0.210,0.212,0.214,0.216,0.218,0.220,      000384
0018      CO.222,0.224,0.226,0.228,0.230,0.232,0.234,0.236,0.238,0.240,0.242,      000385
0019      CO.244,0.246,0.248,0.250,0.252,0.254,0.256,0.258,0.260,0.262,0.264,      000386
0020      CO.266,0.268,0.270,0.272,0.274,0.276,0.278,0.280,0.282,0.284,0.286,      000387
0021      CO.288,0.290,0.292,0.294,0.296,0.298,0.300,0.302,0.304,0.306,0.308,      000388
0022      CO.310,0.312,0.314,0.316,0.318,0.320,0.322,0.324,0.326,0.328,0.330,      000389
0023      CO.332,0.334,0.336,0.338,0.340,0.342,0.344,0.346,0.348,0.350,0.352,      000390
0024      CO.354,0.356,0.358,0.360,0.362,0.364,0.366,0.368,0.370,0.372,0.374,      000391
0025      CO.376,0.378,0.380,0.382,0.384,0.386,0.388,0.390,0.392,0.394,0.396,      000392
0026      CO.398,0.400,0.402,0.404,0.406,0.408,0.410,0.412,0.414,0.416,0.418,      000393
0027      CO.420,0.422,0.424,0.426,0.428,0.430,0.432,0.434,0.436,0.438,0.440,      000394
0028      CO.442,0.444,0.446,0.448,0.450,0.452,0.454,0.456,0.458,0.460,0.462,      000395
0029      CO.464,0.466,0.468,0.470,0.472,0.474,0.476,0.478,0.480,0.482,0.484,      000396
0030      CO.486,0.488,0.490,0.492,0.494,0.496,0.498,0.500,0.502,0.504,0.506,      000397
0031      CO.508,0.510,0.512,0.514,0.516,0.518,0.520,0.522,0.524,0.526,0.528,      000398
0032      CO.530,0.532,0.534,0.536,0.538,0.540,0.542,0.544,0.546,0.548,0.550,      000399
0033      CO.552,0.554,0.556,0.558,0.560,0.562,0.564,0.566,0.568,0.570,0.572,      000400
0034      CO.574,0.576,0.578,0.580,0.582,0.584,0.586,0.588,0.590,0.592,0.594,      000401
0035      CO.596,0.598,0.600,0.602,0.604,0.606,0.608,0.610,0.612,0.614,0.616,      000402
0036      CO.618,0.620,0.622,0.624,0.626,0.628,0.630,0.632,0.634,0.636,0.638,      000403
0037      CO.640,0.642,0.644,0.646,0.648,0.650,0.652,0.654,0.656,0.658,0.660,      000404
0038      CO.662,0.664,0.666,0.668,0.670,0.672,0.674,0.676,0.678,0.680,0.682,      000405
0039      CO.684,0.686,0.688,0.690,0.692,0.694,0.696,0.698,0.700,0.702,0.704,      000406
0040      CO.706,0.708,0.710,0.712,0.714,0.716,0.718,0.720,0.722,0.724,0.726,      000407
0041      CO.728,0.730,0.732,0.734,0.736,0.738,0.740,0.742,0.744,0.746,0.748,      000408
0042      CO.750,0.752,0.754,0.756,0.758,0.760,0.762,0.764,0.766,0.768,0.770,      000409
0043      CO.772,0.774,0.776,0.778,0.780,0.782,0.784,0.786,0.788,0.790,0.792,      000410
0044      CO.794,0.796,0.798,0.800,0.802,0.804,0.806,0.808,0.810,0.812,0.814,      000411
0045      CO.816,0.818,0.820,0.822,0.824,0.826,0.828,0.830,0.832,0.834,0.836,      000412
0046      CO.838,0.840,0.842,0.844,0.846,0.848,0.850,0.852,0.854,0.856,0.858,      000413
0047      CO.860,0.862,0.864,0.866,0.868,0.870,0.872,0.874,0.876,0.878,0.880,      000414
0048      CO.882,0.884,0.886,0.888,0.890,0.892,0.894,0.896,0.898,0.900,0.902,      000415
0049      CO.904,0.906,0.908,0.910,0.912,0.914,0.916,0.918,0.920,0.922,0.924,      000416
0050      CO.926,0.928,0.930,0.932,0.934,0.936,0.938,0.940,0.942,0.944,0.946,      000417
0051      CO.948,0.950,0.952,0.954,0.956,0.958,0.960,0.962,0.964,0.966,0.968,      000418
0052      CO.970,0.972,0.974,0.976,0.978,0.980,0.982,0.984,0.986,0.988,0.990,      000419
0053      CO.992,0.994,0.996,0.998,1.000,1.002,1.004,1.006,1.008,1.010,1.012,      000420
0054      CO.1014,1.016,1.018,1.020,1.022,1.024,1.026,1.028,1.030,1.032,1.034,      000421
0055      CO.1036,1.038,1.040,1.042,1.044,1.046,1.048,1.050,1.052,1.054,1.056,      000422
0056      CO.1058,1.060,1.062,1.064,1.066,1.068,1.070,1.072,1.074,1.076,1.078,      000423
0057      CO.1080,1.082,1.084,1.086,1.088,1.090,1.092,1.094,1.096,1.098,1.100,      000424
0058      CO.1102,1.104,1.106,1.108,1.110,1.112,1.114,1.116,1.118,1.120,1.122,      000425
0059      CO.1124,1.126,1.128,1.130,1.132,1.134,1.136,1.138,1.140,1.142,1.144,      000426
0060      CO.1146,1.148,1.150,1.152,1.154,1.156,1.158,1.160,1.162,1.164,1.166,      000427
0061      CO.1168,1.170,1.172,1.174,1.176,1.178,1.180,1.182,1.184,1.186,1.188,      000428
0062      CO.1190,1.192,1.194,1.196,1.198,1.200,1.202,1.204,1.206,1.208,1.210,      000429
0063      CO.1212,1.214,1.216,1.218,1.220,1.222,1.224,1.226,1.228,1.230,1.232,      000430
0064      CO.1234,1.236,1.238,1.240,1.242,1.244,1.246,1.248,1.250,1.252,1.254,      000431
0065      CO.1256,1.258,1.260,1.262,1.264,1.266,1.268,1.270,1.272,1.274,1.276,      000432
0066      CO.1278,1.280,1.282,1.284,1.286,1.288,1.290,1.292,1.294,1.296,1.298,      000433
0067      CO.1300,1.302,1.304,1.306,1.308,1.310,1.312,1.314,1.316,1.318,1.320,      000434
0068      CO.1322,1.324,1.326,1.328,1.330,1.332,1.334,1.336,1.338,1.340,1.342,      000435
0069      CO.1344,1.346,1.348,1.350,1.352,1.354,1.356,1.358,1.360,1.362,1.364,      000436
0070      CO.1366,1.368,1.370,1.372,1.374,1.376,1.378,1.380,1.382,1.384,1.386,      000437
0071      CO.1388,1.390,1.392,1.394,1.396,1.398,1.400,1.402,1.404,1.406,1.408,      000438
0072      CO.1410,1.412,1.414,1.416,1.418,1.420,1.422,1.424,1.426,1.428,1.430,      000439
0073      CO.1432,1.434,1.436,1.438,1.440,1.442,1.444,1.446,1.448,1.450,1.452,      000440
0074      CO.1454,1.456,1.458,1.460,1.462,1.464,1.466,1.468,1.470,1.472,1.474,      000441
0075      CO.1476,1.478,1.480,1.482,1.484,1.486,1.488,1.490,1.492,1.494,1.496,      000442
0076      CO.1498,1.500,1.502,1.504,1.506,1.508,1.510,1.512,1.514,1.516,1.518,      000443
0077      CO.1520,1.522,1.524,1.526,1.528,1.530,1.532,1.534,1.536,1.538,1.540,      000444
0078      CO.1542,1.544,1.546,1.548,1.550,1.552,1.554,1.556,1.558,1.560,1.562,      000445
0079      CO.1564,1.566,1.568,1.570,1.572,1.574,1.576,1.578,1.580,1.582,1.584,      000446
0080      CO.1586,1.588,1.590,1.592,1.594,1.596,1.598,1.600,1.602,1.604,1.606,      000447
0081      CO.1608,1.610,1.612,1.614,1.616,1.618,1.620,1.622,1.624,1.626,1.628,      000448
0082      CO.1630,1.632,1.634,1.636,1.638,1.640,1.642,1.644,1.646,1.648,1.650,      000449
0083      CO.1652,1.654,1.656,1.658,1.660,1.662,1.664,1.666,1.668,1.670,1.672,      000450
0084      CO.1674,1.676,1.678,1.680,1.682,1.684,1.686,1.688,1.690,1.692,1.694,      000451
0085      CO.1696,1.698,1.700,1.702,1.704,1.706,1.708,1.710,1.712,1.714,1.716,      000452
0086      CO.1718,1.720,1.722,1.724,1.726,1.728,1.730,1.732,1.734,1.736,1.738,      000453
0087      CO.1740,1.742,1.744,1.746,1.748,1.750,1.752,1.754,1.756,1.758,1.760,      000454
0088      CO.1762,1.764,1.766,1.768,1.770,1.772,1.774,1.776,1.778,1.780,1.782,      000455
0089      CO.1784,1.786,1.788,1.790,1.792,1.794,1.796,1.798,1.800,1.802,1.804,      000456
0090      CO.1806,1.808,1.810,1.812,1.814,1.816,1.818,1.820,1.822,1.824,1.826,      000457
0091      CO.1828,1.830,1.832,1.834,1.836,1.838,1.840,1.842,1.844,1.846,1.848,      000458
0092      CO.1850,1.852,1.854,1.856,1.858,1.860,1.862,1.864,1.866,1.868,1.870,      000459
0093      CO.1872,1.874,1.876,1.878,1.880,1.882,1.884,1.886,1.888,1.890,1.892,      000460
0094      CO.1894,1.896,1.898,1.900,1.902,1.904,1.906,1.908,1.910,1.912,1.914,      000461
0095      CO.1916,1.918,1.920,1.922,1.924,1.926,1.928,1.930,1.932,1.934,1.936,      000462
0096      CO.1938,1.940,1.942,1.944,1.946,1.948,1.950,1.952,1.954,1.956,1.958,      000463
0097      CO.1960,1.962,1.964,1.966,1.968,1.970,1.972,1.974,1.976,1.978,1.980,      000464
0098      CO.1982,1.984,1.986,1.988,1.990,1.992,1.994,1.996,1.998,2.000,2.002,      000465
0099      CO.2004,2.006,2.008,2.010,2.012,2.014,2.016,2.018,2.020,2.022,2.024,      000466
0100      CO.2026,2.028,2.030,2.032,2.034,2.036,2.038,2.040,2.042,2.044,2.046,      000467
0101      CO.2048,2.050,2.052,2.054,2.056,2.058,2.060,2.062,2.064,2.066,2.068,      000468
0102      CO.2070,2.072,2.074,2.076,2.078,2.080,2.082,2.084,2.086,2.088,2.090,      000469
0103      CO.2092,2.094,2.096,2.098,2.100,2.102,2.104,2.106,2.108,2.110,2.112,      000470
0104      CO.2114,2.116,2.118,2.120,2.122,2.124,2.126,2.128,2.130,2.132,2.134,      000471
0105      CO.2136,2.138,2.140,2.142,2.144,2.146,2.148,2.150,2.152,2.154,2.156,      000472
0106      CO.2158,2.160,2.162,2.164,2.166,2.168,2.170,2.172,2.174,2.176,2.178,      000473
0107      CO.2180,2.182,2.184,2.186,2.188,2.190,2.192,2.194,2.196,2.198,2.200,      000474
0108      CO.2202,2.204,2.206,2.208,2.210,2.212,2.214,2.216,2.218,2.220,2.222,      000475
0109      CO.2224,2.226,2.228,2.230,2.232,2.234,2.236,2.238,2.240,2.242,2.244,      000476
0110      CO.2246,2.248,2.250,2.252,2.254,2.256,2.258,2.260,2.262,2.264,2.266,      000477
0111      CO.2268,2.270,2.272,2.274,2.276,2.278,2.280,2.282,2.284,2.286,2.288,      000478
0112      CO.2290,2.292,2.294,2.296,2.298,2.300,2.302,2.304,2.306,2.308,2.310,      000479
0113      CO.2312,2.314,2.316,2.318,2.320,2.322,2.324,2.326,2.328,2.330,2.332,      000480
0114      CO.2334,2.336,2.338,2.340,2.342,2.344,2.346,2.348,2.350,2.352,2.354,      000481
0115      CO.2356,2.358,2.360,2.362,2.364,2.366,2.368,2.370,2.372,2.374,2.376,      000482
0116      CO.2378,2.380,2.382,2.384,2.386,2.388,2.390,2.392,2.394,2.396,2.398,      000483
0117      CO.2400,2.402,2.404,2.406,2.408,2.410,2.412,2.414,2.416,2.418,2.420,      000484
0118      CO.2422,2.424,2.426,2.428,2.430,2.432,2.434,2.436,2.438,2.440,2.442,      000485
0119      CO.2444,2.446,2.448,2.450,2.452,2.454,2.456,2.458,2.460,2.462,2.464,      000486
0120      CO.2466,2.468,2.470,2.472,2.474,2.476,2.478,2.480,2.482,2.484,2.486,      000487
0121      CO.2488,2.490,2.492,2.494,2.496,2.498,2.500,2.502,2.504,2.506,2.508,      000488
0122      CO.2510,2.512,2.514,2.516,2.518,2.520,2.522,2.524,2.526,2.528,2.530,      000489
0123      CO.2532,2.534,2.536,2.538,2.540,2.542,2.544,2.546,2.548,2.550,2.552,      000490
0124      CO.2554,2.556,2.558,2.560,2.562,2.564,2.566,2.568,2.570,2.572,2.574,      000491
0125      CO.2576,2.578,2.580,2.582,2.584,2.586,2.588,2.590,2.592,2.594,2.596,      000492
0126      CO.2598,2.600,2.602,2.604,2.606,2.608,2.610,2.612,2.614,2.616,2.618,      000493
0127      CO.2620,2.622,2.624,2.626,2.628,2.630,2.632,2.634,2.636,2.638,2.640,      000494
0128      CO.2642,2.644,2.646,2.648,2.650,2.652,2.654,2.656,2.658,2.660,2.662,      000495
0129      CO.2664,2.666,2.668,2.670,2.672,2.674,2.676,2.678,2.680,2.682,2.684,      000496
0130      CO.2686,2.688,2.690,2.692,2.694,2.696,2.698,2.700,2.702,2.704,2.706,      000497
0131      CO.2708,2.710,2.712,2.714,2.716,2.718,2.720,2.722,2.724,2.726,2.728,      000498
0132      CO.2730,2.732,2.734,2.736,2.738,2.740,2.742,2.744,2.746,2.748,2.750,      000499
0133      CO.2752,2.754,2.756,2.758,2.760,2.762,2.764,2.766,2.768,2.770,2.772,      000500
0134      CO.2774,2.776,2.778,2.780,2.782,2.784,2.786,2.788,2.790,2.792,2.794,      000501
0135      CO.2796,2.798,2.800,2.802,2.804,2.806,2.808,2.810,2.812,2.814,2.816,      000502
0136      CO.2818,2.820,2.822,2.824,2.826,2.828,2.830,2.832,2.834,2.836,2.838,      000503
0137      CO.2840,2.842,2.844,2.846,2.848,2.850,2.852,2.854,2.856,2.858,2.860,      000504
0138      CO.2862,2.864,2.866,2.868,2.870,2.872,2.874,2.876,2.878,2.880,2.882,      000505
0139      CO.2884,2.886,2.888,2.890,2.892,2.894,2.896,2.898,2.900,2.902,2.904,      000506
0140      CO.2906,2.908,2.910,2.912,2.914,2.916,2.918,2.920,2.922,2.924,2.926,      000507
0141      CO.2928,2.930,2.932,2.934,2.936,2.938,2.940,2.942,2.944,2.946,2.948,      000508
0142      CO.2950,2.952,2.954,2.956,2.958,2.960,2.962,2.964,2.966,2.968,2.970,      000509
0143      CO.2972,2.974,2.976,2.978,2.980,2.982,2.984,2.986,2.988,2.990,2.992,      000510
0144      CO.2994,2.996,2.998,3.000,3.002,3.004,3.006,3.008,3.010,3.012,3.014,      000511
0145      CO.3016,3.018,3.020,3.022,3.024,3.026,3.028,3.030,3.032,3.034,3.036,      000512
0146      CO.3038,3.040,3.042,3.044,3.046,3.048,3.050,3.052,3.054,3.056,3.058,      000513
0147      CO.3060,3.062,3.064,3.066,3.068,3.070,3.072,3.074,3.076,3.078,3.080,      000514
0148      CO.3082,3.084,3.086,3.088,3.090,3.092,3.094,3.096,3.098,3.100,3.102,      000515
0149      CO.3104,3.106,3.108,3.110,3.112,3.114,3.116,3.118,3.120,3.122,3.124,      000516
0150      CO.3126,3.128,3.130,3.132,3.134,3.136,3.138,3.140,3.142,3.144,3.146,      000517
0151      CO.3148,3.150,3.152,3.154,3.156,3.158,3.160,3.162,3.164,3.166,3.168,      000518
0152      CO.3170,3.172,3.174,3.176,3.178,3.180,3.182,3.184,3.186,3.188,3.190,      000519
0153      CO.3192,3.194,3.196,3.198,3.200,3.202,3.204,3.206,3.208,3.210,3.212,      000520
0154      CO.3214,3.216,3.218,3.220,3.222,3.224,3.226,3.228,3.230,3.232,3.234,      000521
0155      CO.3236,3.238,3.240,3.242,3.244,3.246,3.248,3.250,3.252,3.254,3.256,      000522
0156      CO.3258,3.260,3.262,3.264,3.266,3.268,3.270,3.272,3.274,3.276,3.278,      000523
0157      CO.3280,3.282,3.
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DOS FORTRAN IV 360N-FO-479 3-8      F5      DATE 01/09/78      TIME 13.26.00
0045 VEL=(WD/3600.)/(RHO*AORIFI)*144.
0046 Q=0.5*RHO*(VEL**2)/(144.*32.2)
0047 FVD=Q*AK
0048 P6=P2-FVD
0049 IFIP6.LT.0.) P6=0.0
0050 R2MN=R1-XLTPR*TAN(BETA)-(XLMX-XLTPR)*TAN(BETAP)
0051 PAVG=(P2+P6)/2.
0052 D2=2.*R2MN
0053 RF=(P2-PAVG)*(PI/4.)*(D0**2-D2**2)+P6*(PI/4.)*(D0**2)
0054 AMRF=-RF/XKA
0055 IF(N.EQ.0) GO TO 4
0056 IF(ABS(FVD-FVDP).GT. ERROR) GO TO 4
C IF PROGRAM PASSES THIS LAST TEST, ITERATION HAS CONVERGED
6 F5=(X2-X5)-FVD
JJJ=MOD(M1,100)
IF(JJJ.NE.0) GO TO 1000
WRITE(3,1100) AORIF,AK,Q,FVC,F5,DELTA
1100 FORMAT( 6E13.4)
1000 CONTINUE
RETURN
4 N=N+1
FVDP=FVD
IF(N.LE.1000) GO TO 5
WRITE(3,200) DOLD,DELTA,X2,X5,X10,AMRF,AORIF
200 FORMAT( / 3X,' VARIABLE ORIFICE ITERATION FAILURE, DOLD= ',F10.5,
C , DELTA= ',F10.5/,F10.5)
M1=NMAX+1000
GO TO 6
5 IF(N.LT.3) GO TO 7
DOLD=DELTA
D02=DOLD
D2=ADJVO+AMDP+AMRF
IF(D02.EQ.D01) GO TO 7
XM=(D2-D1)/(D02-D01)
B=D2-D02*XM
IF(XM.EQ.1.) GO TO 7
DELTA=B/(1.-XM)
D01=D02
D1=D2
GO TO 2
7 DOLD=DELTA
D01=DELTA
D1=ADJVO+AMDP+AMRF
8 DELTA=(ADJVO+AMDP+AMRF+DOLD)/2.0
GO TO 2
END
00422
00423
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DOS	FORTTRAN	IV	360N-F0-479	3-8	F6	DATE	01/09/78	TIME	13.26.19	PAGE	0001
0001					FUNCTION F6(X1,X5)				000468		
0002		C			IDLE RELIEF VALVE PRESSURE DRUP				000469		
0003					COMMON RHO,VISC.PI,PAMB,PCCNL,P5				000470		
0004					COMMON/AAA/ M1				000471		
0005					COMMON /SIX/ XK,RD, SAL				000472		
0006					PI=X1				000473		
0007					R1=0.31				000474		
0008					SFL=0.50				000475		
0009					FRV=((SFL-SAL)*XK+(P5*14.696/25.92-PI)*PI*(PD**2))/(PI*(R1**2))				000476		
0010					F6=X5-X1-FRV				000477		
0011					JJJ=MOD(M1,100)				000478		
0012					IF(JJJ.NE.0) GO TO 10CC				000479		
0013					WRITE(3,1100) FRV,F6				000480		
0014					1100 FORMAT( 2E13.4)				000481		
0015					1000 CONTINUE				000482		
0016					RETURN				000483		
					END				000484		

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D05 FORTRAN IV 360N-FO-479 3-8      F7      DATE 01/09/78      TIME 13.26.33
0001      FUNCTION F7(X2,X6,XS)      000485
0002      C      PRESSURE DROP ACROSS VAPOR SEPARATOR      000486
0003      COMMON RHO,VISC,PI,PAPB,PCCNL,PS      000487
0004      COMMON/AAA/ M1      000488
0005      DIMENSION FLO(100)      000489
0006      DATA FLO /1.,1.,16.,0.,0.,10.,20.,30.,35.,40.,45.,47.5,50.,      000490
0007      C 52.5,55.,57.5,60.,62.5,65.,70.,73.5,77.,81.,85.,89.,93.,97.,100.,      000491
0008      C 22.5,26.8,31.8,37.5,43.4,50.,57.,63.,69.,75.,81.,87.,93.,99.,105.,111.,117.,123.,129.,135.,141.,147.,153.,159.,165.,171.,177.,183.,189.,195.,201.,207.,213.,219.,225.,231.,237.,243.,249.,255.,261.,267.,273.,279.,285.,291.,297.,303.,309.,315.,321.,327.,333.,339.,345.,351.,357.,363.,369.,375.,381.,387.,393.,399.,405.,411.,417.,423.,429.,435.,441.,447.,453.,459.,465.,471.,477.,483.,489.,495.,501.,507.,513.,519.,525.,531.,537.,543.,549.,555.,561.,567.,573.,579.,585.,591.,597.,603.,609.,615.,621.,627.,633.,639.,645.,651.,657.,663.,669.,675.,681.,687.,693.,699.,705.,711.,717.,723.,729.,735.,741.,747.,753.,759.,765.,771.,777.,783.,789.,795.,801.,807.,813.,819.,825.,831.,837.,843.,849.,855.,861.,867.,873.,879.,885.,891.,897.,903.,909.,915.,921.,927.,933.,939.,945.,951.,957.,963.,969.,975.,981.,987.,993.,999.,1005.,1011.,1017.,1023.,1029.,1035.,1041.,1047.,1053.,1059.,1065.,1071.,1077.,1083.,1089.,1095.,1101.,1107.,1113.,1119.,1125.,1131.,1137.,1143.,1149.,1155.,1161.,1167.,1173.,1179.,1185.,1191.,1197.,1203.,1209.,1215.,1221.,1227.,1233.,1239.,1245.,1251.,1257.,1263.,1269.,1275.,1281.,1287.,1293.,1299.,1305.,1311.,1317.,1323.,1329.,1335.,1341.,1347.,1353.,1359.,1365.,1371.,1377.,1383.,1389.,1395.,1401.,1407.,1413.,1419.,1425.,1431.,1437.,1443.,1449.,1455.,1461.,1467.,1473.,1479.,1485.,1491.,1497.,1503.,1509.,1515.,1521.,1527.,1533.,1539.,1545.,1551.,1557.,1563.,1569.,1575.,1581.,1587.,1593.,1599.,1605.,1611.,1617.,1623.,1629.,1635.,1641.,1647.,1653.,1659.,1665.,1671.,1677.,1683.,1689.,1695.,1701.,1707.,1713.,1719.,1725.,1731.,1737.,1743.,1749.,1755.,1761.,1767.,1773.,1779.,1785.,1791.,1797.,1803.,1809.,1815.,1821.,1827.,1833.,1839.,1845.,1851.,1857.,1863.,1869.,1875.,1881.,1887.,1893.,1899.,1905.,1911.,1917.,1923.,1929.,1935.,1941.,1947.,1953.,1959.,1965.,1971.,1977.,1983.,1989.,1995.,2001.,2007.,2013.,2019.,2025.,2031.,2037.,2043.,2049.,2055.,2061.,2067.,2073.,2079.,2085.,2091.,2097.,2103.,2109.,2115.,2121.,2127.,2133.,2139.,2145.,2151.,2157.,2163.,2169.,2175.,2181.,2187.,2193.,2199.,2205.,2211.,2217.,2223.,2229.,2235.,2241.,2247.,2253.,2259.,2265.,2271.,2277.,2283.,2289.,2295.,2301.,2307.,2313.,2319.,2325.,2331.,2337.,2343.,2349.,2355.,2361.,2367.,2373.,2379.,2385.,2391.,2397.,2403.,2409.,2415.,2421.,2427.,2433.,2439.,2445.,2451.,2457.,2463.,2469.,2475.,2481.,2487.,2493.,2499.,2505.,2511.,2517.,2523.,2529.,2535.,2541.,2547.,2553.,2559.,2565.,2571.,2577.,2583.,2589.,2595.,2601.,2607.,2613.,2619.,2625.,2631.,2637.,2643.,2649.,2655.,2661.,2667.,2673.,2679.,2685.,2691.,2697.,2703.,2709.,2715.,2721.,2727.,2733.,2739.,2745.,2751.,2757.,2763.,2769.,2775.,2781.,2787.,2793.,2799.,2805.,2811.,2817.,2823.,2829.,2835.,2841.,2847.,2853.,2859.,2865.,2871.,2877.,2883.,2889.,2895.,2901.,2907.,2913.,2919.,2925.,2931.,2937.,2943.,2949.,2955.,2961.,2967.,2973.,2979.,2985.,2991.,2997.,3003.,3009.,3015.,3021.,3027.,3033.,3039.,3045.,3051.,3057.,3063.,3069.,3075.,3081.,3087.,3093.,3099.,3105.,3111.,3117.,3123.,3129.,3135.,3141.,3147.,3153.,3159.,3165.,3171.,3177.,3183.,3189.,3195.,3201.,3207.,3213.,3219.,3225.,3231.,3237.,3243.,3249.,3255.,3261.,3267.,3273.,3279.,3285.,3291.,3297.,3303.,3309.,3315.,3321.,3327.,3333.,3339.,3345.,3351.,3357.,3363.,3369.,3375.,3381.,3387.,3393.,3399.,3405.,3411.,3417.,3423.,3429.,3435.,3441.,3447.,3453.,3459.,3465.,3471.,3477.,3483.,3489.,3495.,3501.,3507.,3513.,3519.,3525.,3531.,3537.,3543.,3549.,3555.,3561.,3567.,3573.,3579.,3585.,3591.,3597.,3603.,3609.,3615.,3621.,3627.,3633.,3639.,3645.,3651.,3657.,3663.,3669.,3675.,3681.,3687.,3693.,3699.,3705.,3711.,3717.,3723.,3729.,3735.,3741.,3747.,3753.,3759.,3765.,3771.,3777.,3783.,3789.,3795.,3801.,3807.,3813.,3819.,3825.,3831.,3837.,3843.,3849.,3855.,3861.,3867.,3873.,3879.,3885.,3891.,3897.,3903.,3909.,3915.,3921.,3927.,3933.,3939.,3945.,3951.,3957.,3963.,3969.,3975.,3981.,3987.,3993.,3999.,4005.,4011.,4017.,4023.,4029.,4035.,4041.,4047.,4053.,4059.,4065.,4071.,4077.,4083.,4089.,4095.,4101.,4107.,4113.,4119.,4125.,4131.,4137.,4143.,4149.,4155.,4161.,4167.,4173.,4179.,4185.,4191.,4197.,4203.,4209.,4215.,4221.,4227.,4233.,4239.,4245.,4251.,4257.,4263.,4269.,4275.,4281.,4287.,4293.,4299.,4305.,4311.,4317.,4323.,4329.,4335.,4341.,4347.,4353.,4359.,4365.,4371.,4377.,4383.,4389.,4395.,4401.,4407.,4413.,4419.,4425.,4431.,4437.,4443.,4449.,4455.,4461.,4467.,4473.,4479.,4485.,4491.,4497.,4503.,4509.,4515.,4521.,4527.,4533.,4539.,4545.,4551.,4557.,4563.,4569.,4575.,4581.,4587.,4593.,4599.,4605.,4611.,4617.,4623.,4629.,4635.,4641.,4647.,4653.,4659.,4665.,4671.,4677.,4683.,4689.,4695.,4701.,4707.,4713.,4719.,4725.,4731.,4737.,4743.,4749.,4755.,4761.,4767.,4773.,4779.,4785.,4791.,4797.,4803.,4809.,4815.,4821.,4827.,4833.,4839.,4845.,4851.,4857.,4863.,4869.,4875.,4881.,4887.,4893.,4899.,4905.,4911.,4917.,4923.,4929.,4935.,4941.,4947.,4953.,4959.,4965.,4971.,4977.,4983.,4989.,4995.,5001.,5007.,5013.,5019.,5025.,5031.,5037.,5043.,5049.,5055.,5061.,5067.,5073.,5079.,5085.,5091.,5097.,5103.,5109.,5115.,5121.,5127.,5133.,5139.,5145.,5151.,5157.,5163.,5169.,5175.,5181.,5187.,5193.,5199.,5205.,5211.,5217.,5223.,5229.,5235.,5241.,5247.,5253.,5259.,5265.,5271.,5277.,5283.,5289.,5295.,5301.,5307.,5313.,5319.,5325.,5331.,5337.,5343.,5349.,5355.,5361.,5367.,5373.,5379.,5385.,5391.,5397.,5403.,5409.,5415.,5421.,5427.,5433.,5439.,5445.,5451.,5457.,5463.,5469.,5475.,5481.,5487.,5493.,5499.,5505.,5511.,5517.,5523.,5529.,5535.,5541.,5547.,5553.,5559.,5565.,5571.,5577.,5583.,5589.,5595.,5601.,5607.,5613.,5619.,5625.,5631.,5637.,5643.,5649.,5655.,5661.,5667.,5673.,5679.,5685.,5691.,5697.,5703.,5709.,5715.,5721.,5727.,5733.,5739.,5745.,5751.,5757.,5763.,5769.,5775.,5781.,5787.,5793.,5799.,5805.,5811.,5817.,5823.,5829.,5835.,5841.,5847.,5853.,5859.,5865.,5871.,5877.,5883.,5889.,5895.,5901.,5907.,5913.,5919.,5925.,5931.,5937.,5943.,5949.,5955.,5961.,5967.,5973.,5979.,5985.,5991.,5997.,6003.,6009.,6015.,6021.,6027.,6033.,6039.,6045.,6051.,6057.,6063.,6069.,6075.,6081.,6087.,6093.,6099.,6105.,6111.,6117.,6123.,6129.,6135.,6141.,6147.,6153.,6159.,6165.,6171.,6177.,6183.,6189.,6195.,6201.,6207.,6213.,6219.,6225.,6231.,6237.,6243.,6249.,6255.,6261.,6267.,6273.,6279.,6285.,6291.,6297.,6303.,6309.,6315.,6321.,6327.,6333.,6339.,6345.,6351.,6357.,6363.,6369.,6375.,6381.,6387.,6393.,6399.,6405.,6411.,6417.,6423.,6429.,6435.,6441.,6447.,6453.,6459.,6465.,6471.,6477.,6483.,6489.,6495.,6501.,6507.,6513.,6519.,6525.,6531.,6537.,6543.,6549.,6555.,6561.,6567.,6573.,6579.,6585.,6591.,6597.,6603.,6609.,6615.,6621.,6627.,6633.,6639.,6645.,6651.,6657.,6663.,6669.,6675.,6681.,6687.,6693.,6699.,6705.,6711.,6717.,6723.,6729.,6735.,6741.,6747.,6753.,6759.,6765.,6771.,6777.,6783.,6789.,6795.,6801.,6807.,6813.,6819.,6825.,6831.,6837.,6843.,6849.,6855.,6861.,6867.,6873.,6879.,6885.,6891.,6897.,6903.,6909.,6915.,6921.,6927.,6933.,6939.,6945.,6951.,6957.,6963.,6969.,6975.,6981.,6987.,6993.,6999.,7005.,7011.,7017.,7023.,7029.,7035.,7041.,7047.,7053.,7059.,7065.,7071.,7077.,7083.,7089.,7095.,7101.,7107.,7113.,7119.,7125.,7131.,7137.,7143.,7149.,7155.,7161.,7167.,7173.,7179.,7185.,7191.,7197.,7203.,7209.,7215.,7221.,7227.,7233.,7239.,7245.,7251.,7257.,7263.,7269.,7275.,7281.,7287.,7293.,7299.,7305.,7311.,7317.,7323.,7329.,7335.,7341.,7347.,7353.,7359.,7365.,7371.,7377.,7383.,7389.,7395.,7401.,7407.,7413.,7419.,7425.,7431.,7437.,7443.,7449.,7455.,7461.,7467.,7473.,7479.,7485.,7491.,7497.,7503.,7509.,7515.,7521.,7527.,7533.,7539.,7545.,7551.,7557.,7563.,7569.,7575.,7581.,7587.,7593.,7599.,7605.,7611.,7617.,7623.,7629.,7635.,7641.,7647.,7653.,7659.,7665.,7671.,7677.,7683.,7689.,7695.,7701.,7707.,7713.,7719.,7725.,7731.,7737.,7743.,7749.,7755.,7761.,7767.,7773.,7779.,7785.,7791.,7797.,7803.,7809.,7815.,7821.,7827.,7833.,7839.,7845.,7851.,7857.,7863.,7869.,7875.,7881.,7887.,7893.,7899.,7905.,7911.,7917.,7923.,7929.,7935.,7941.,7947.,7953.,7959.,7965.,7971.,7977.,7983.,7989.,7995.,8001.,8007.,8013.,8019.,8025.,8031.,8037.,8043.,8049.,8055.,8061.,8067.,8073.,8079.,8085.,8091.,8097.,8103.,8109.,8115.,8121.,8127.,8133.,8139.,8145.,8151.,8157.,8163.,8169.,8175.,8181.,8187.,8193.,8199.,8205.,8211.,8217.,8223.,8229.,8235.,8241.,8247.,8253.,8259.,8265.,8271.,8277.,8283.,8289.,8295.,8301.,8307.,8313.,8319.,8325.,8331.,8337.,8343.,8349.,8355.,8361.,8367.,8373.,8379.,8385.,8391.,8397.,8403.,8409.,8415.,8421.,8427.,8433.,8439.,8445.,8451.,8457.,8463.,8469.,8475.,8481.,8487.,8493.,8499.,8505.,8511.,8517.,8523.,8529.,8535.,8541.,8547.,8553.,8559.,8565.,8571.,8577.,8583.,8589.,8595.,8601.,8607.,8613.,8619.,8625.,8631.,8637.,8643.,8649.,8655.,8661.,8667.,8673.,8679.,8685.,8691.,8697.,8703.,8709.,8715.,8721.,8727.,8733.,8739.,8745.,8751.,8757.,8763.,8769.,8775.,8781.,8787.,8793.,8799.,8805.,8811.,8817.,8823.,8829.,8835.,8841.,8847.,8853.,8859.,8865.,8871.,8877.,8883.,8889.,8895.,8901.,8907.,8913.,8919.,8925.,8931.,8937.,8943.,8949.,8955.,8961.,8967.,8973.,8979.,8985.,8991.,8997.,9003.,9009.,9015.,9021.,9027.,9033.,9039.,9045.,9051.,9057.,9063.,9069.,9075.,9081.,9087.,9093.,9099.,9105.,9111.,9117.,9123.,9129.,9135.,9141.,9147.,9153.,9159.,9165.,9171.,9177.,9183.,9189.,9195.,9201.,9207.,9213.,9219.,9225.,9231.,9237.,9243.,9249.,9255.,9261.,9267.,9273.,9279.,9285.,9291.,9297.,9303.,9309.,9315.,9321.,9327.,9333.,9339.,9345.,9351.,9357.,9363.,9369.,9375.,9381.,9387.,9393.,9399.,9405.,9411.,9417.,9423.,9429.,9435.,9441.,9447.,9453.,9459.,9465.,9471.,9477.,9483.,9489.,9495.,9501.,9507.,9513.,9519.,9525.,9531.,9537.,9543.,9549.,9555.,9561.,9567.,9573.,9579.,9585.,9591.,9597.,9603.,9609.,9615.,9621.,9627.,9633.,9639.,9645.,9651.,9657.,9663.,9669.,9675.,9681.,9687.,9693.,9699.,9705.,9711.,9717.,9723.,9729.,9735.,9741.,9747.,9753.,9759.,9765.,9771.,9777.,9783.,9789.,9795.,9801.,9807.,9813.,9819.,9825.,9831.,9837.,9843.,9849.,9855.,9861.,9867.,9873.,9879.,9885.,9891.,9897.,9903.,9909.,9915.,9921.,9927.,9933.,9939.,9945.,9951.,9957.,9963.,9969.,9975.,9981.,9987.,9993.,9999.,10005.,10011.,10017.,10023.,10029.,10035.,10041.,10047.,10053.,10059.,10065.,10071.,10077.,10083.,10089.,10095.,10101.,10107.,10113.,10119.,10125.,10131.,10137.,10143.,10149.,10155.,10161.,10167.,10173.,10179.,10185.,10191.,10197.,10203.,10209.,10215.,10221.,10227.,10233.,10239.,10245.,10251.,10257.,10263.,10269.,10275.,10281.,10287.,10293.,10299.,10305.,10311.,10317.,10323.,10329.,10335.,10341.,10347.,10353.,10359.,10365.,10371.,10377.,10383.,10389.,10395.,10401.,10407.,10413.,10419.,10425.,10431.,10437.,10443.,10449.,10455.,10461.,10467.,10473.,10479.,10485.,10491.,10497.,10503.,10509.,10515.,10521.,10527.,10533.,10539.,10545.,10551.,10557.,10563.,10569.,10575.,10581.,10587.,10593.,10599.,10605.,10611.,10617.,10623.,10629.,10635.,10641.,10647.,10653.,10659.,10665.,10671.,10677.,10683.,10689.,10695.,10701.,10707.,10713.,10719.,10725.,10731.,10737.,10743.,10749.,10755.,10761.,10767.,10773.,10779.,10785.,10791.,10797.,10803.,10809.,10815.,10821.,10827.,10833.,10839.,10845.,10851.,10857.,10863.,10869.,10875.,10881.,10887.,10893.,10899.,10905.,10911.,10917.,10923.,10929.,10935.,10941.,10947.,10953.,10959.,10965.,10971.,10977.,10983.,10989.,10995.,11001.,11007.,11013.,11019.,11025.,11031.,11037.,11043.,11049.,11055.,11061.,11067.,11073.,11079.,11085.,11091.,11097.,11103.,11109.,11115.,11121.,11127.,11133.,11139.,11145.,11151.,11157.,11163.,11169.,11175.,11181.,11187.,11193.,11199.,11205.,11211.,11217.,11223.,11229.,11235.,11241.,11247.,11253.,11259.,11265.,11271.,11277.,11283.,11289.,11295.,11301.,11307.,11313.,11319.,11325.,11331.,11337.,11343.,11349.,11355.,11361.,11367.,11373.,11379.,11385.,11391.,11397.,11403.,11409.,11415.,11421.,11427.,11433.,11439.,11445.,11451.,11457.,11463.,11469.,11475.,11481.,11487.,11493.,11499.,11505.,11511.,11517.,11523.,11529.,11535.,11541.,11547.,11553.,11559.,11565.,11571.,11577.,11583.,11589.,11595.,11601.,11607.,11613.,11619.,11625.,11631.,11637.,11643.,11649.,11655.,11661.,11667.,11673.,11679.,11685.,11691.,11697.,11703.,11709.,11715.,11721.,11727.,11733.,11739.,11745.,11751.,11757.,11763.,11769.,11775.,11781.,11787.,11793.,11799.,11805.,11811.,11817.,11823.,11829.,11835.,11841.,11847.,11853.,11859.,11865.,11871.,11877.,11883.,11889.,11895.,11901.,11907.,11913.,11919.,11925.,11931.,11937.,11943.,11949.,11955.,11961.,11967.,11973.,11979.,11985.,11991.,11997.,12003.,12009.,12015.,12021.,12027.,12033.,12039.,12045.,12051.,12057.,12063.,12069.,12075.,12081.,12087.,12093.,12099.,12105.,12111.,12117.,12123.,12129.,12135.,12141.,12147.,12153.,12159.,12165.,12171.,12177.,12183.,12189.,12195.,12201.,12207.,12213.,12219.,12225.,12231.,12237.,12243.,12249.,12255.,12261.,12267.,12273.,12279.,12285.,12291.,12297.,12303.,12309.,12315.,12321.,12327.,12333.,12339.,12345.,12351.,12357.,12363.,12369.,12375.,12381.,12387.,12393.,12399.,12405.,12411.,12417.,12423.,12429.,12435.,12441.,12447.,12453.,12459.,12465.,12471.,12477.,12483.,12489.,12495.,12501.,12507.,12513.,12519.,12525.,12531.,12537.,12543.,12549.,12555.,12561.,12567.,12573.,12579.,12585.,12591.,12597.,12603.,12609.,12615.,12621.,12627.,12633.,12639.,12645.,12651.,12657.,12663.,12669.,12675.,12681.,12687.,12693.,12699.,12705.,12711.,12717.,12723.,12729.,12735.,12741.,12747.,12753.,12759.,12765.,12771.,12777.,12783.,12789.,12795.,12801.,12807.,12813.,12819.,12825.,12831.,12837.,12843.,12849.,12855.,12861.,12867.,12873.,12879.,12885.,12891.,12897.,12903.,12909.,12915.,12921.,12927.,12933.,12939.,12945.,12951.,12957.,12963.,12969.,12975.,12981.,12987.,12993.,12999.,13005.,13011.,13017.,13023.,13029.,13035.,13041.,13047.,13053.,13059.,13065.,13071.,13077.,13083.,13089.,13095.,13101.,13107.,13113.,13119.,13125.,13131.,13137.,13143.,13149.,13155.,13161.,13167.,13173.,13179.,13185.,13191.,13197.,13203.,13209.,13215.,13221.,13227.,13233.,13239.,13245.,13251.,13257.,13263.,13269.,13275.,13281.,13287.,13293.,13299.,13305.,13311.,13317.,13323.,13329.,13335.,13341.,13347.,13353.,13359.,13365.,13371.,13377.,13383.,13389.,13395.,13401.,13407.,13413.,13419.,13425.,13431.,13437.,13443.,13449.,13455.,13461.,13467.,13473.,13479.,13485.,13491.,13497.,13503.,13509.,13515.,13521.,13527.,13533.,13539.,13545.,13551.,13557.,13563.,13569.,13575.,13581.,13587.,13593.,13599.,13605.,13611.,13617.,13623.,13629.,13635.,13641.,13647.,13653.,13659.,13665.,13671.,13677.,13683.,13689.,13695.,13701.,13707.,13713.,13719.,13725.,13731.,13737.,13743.,13749.,13755.,13761.,13767.,13773.,13779.,13785.,13791.,13797.,13803.,13809.,13815.,13821.,13827.,13833.,13839.,13845.,13851.,138
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0001      FUNCTION F8(X2,XX3,X11)
0002      PRESSURE DROP ACROSS CONTRL UNIT
0003      COMMON RHO,VISC,PI,PAMB,PCCL,P5
0004      COMMON/AAA/ M1
0005      COMMON /EIGHT/ ALFA,ADJ
0006      DIMENSION THROT( 50)
0007      DATA THROT / 1.1,1.17,0.0,0.0,0.5,0.7,0.9,1.1,1.3,1.5,1.7,1.9,2.1,
0008      C2,3,2,5,2,7,2,9,3,1,3,3,3,5,1,0,489,0,566,0,631,0,683,0,722,
0009      C0,748,0,769,0,790,0,812,0,832,0,854,0,876,0,903,0,941,1,0,1,0 /
0010      R8=0.036
0011      RC=0.44475
0012      D=0.09375
0013      H=0.406
0014      XKFC=1.50
0015      W=X11
0016      XBAR=RB*SIN(ALFA)
0017      YBAR=-R*COS(ALFA)
0018      A=4.*(H-YBAR)*(XBAR**2-RC**2+(D/2.)***2+YBAR**2-H**2)**2
0019      B=4.*(H-YBAR)*(XBAR**2-RC**2+(D/2.)***2+YBAR**2-H**2)**2
0020      C=(XBAR**2-RC**2+(D/2.)***2+YBAR**2-H**2)**2
0021      C=C+4.*XBAR**2-H**2-D**2*XBAR**2
0022      Y1=(-B-SQRT(B**2-4.*A*C))/(2.*A)
0023      Y2=(-B+SQRT(B**2-4.*A*C))/(2.*A)
0024      X1=-SQRT((D/2.)***2-(Y1-H)**2)
0025      X2=+SQRT((D/2.)***2-(Y2-H)**2)
0026      A=(H-YBAR)*(X2-X1)
0027      A=A+0.5*(X2*SQRT((D/2.)***2-X2**2)+(D/2.)***2*ARSIN(X2/X1/D))
0028      A=A-0.5*(X1*SQRT((D/2.)***2-X1**2)+(D/2.)***2*ARSIN(X1/D))
0029      A=A-0.5*(X2*SQRT(RC**2-X2**2)+C**2*ARSIN(X2/RC))
0030      A=A-0.5*(X1*SQRT(RC**2-X1**2)+C**2*ARSIN(X1/RC))
0031      AEN=1000.*A
0032      CALL ENGUNB(THROT,1,AEN,0.,CD,IE)
0033      VEL=(W/RHO/A)*(144./3600.)/CD
0034      Q=(0.5*RHO*VEL*ABS(VEL))/(32.*144.)
0035      DP=XKFC*Q
0036      F8=(X2-XX3)-DP
0037      JJJ=MOD(M1,100)
0038      IF(JJJ.NE.0) GO TO 1000
0039      WRITE(3,1100) A,CD,C,DP,F8
0040      1100 FORMAT( 5E13,4)
0041      1000 CONTINUE
0042      RETURN
0043      END

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0001      FUNCTION F9(X3,X4,X11)
0002      MANIFOLD VALVE PRESSURE DRCP
0003      COMMON RHO,VISC,PI,PAMB,PCC,L,P5
0004      COMMON/AAA/ M1
0005      COMMON/XTIME/ XLADJ
0006      DIMENSION ZANIF(100)
0007      DATA ZANIF /1.,1.,4.,0.,0.,0.,100.,200.,0.,1.,2.,3.,2.,88/
0008      XK=0.2070
0009      XLF=0.70
0010      RV=0.090
0011      DPC= XK*(XLF-XLADJ)/(PI*(RV**2))
0012      W=X11
0013      W=W/1.02
0014      CALL ENGUNB(ZANIF,1,W,C,DP,IE)
0015      RHO1=45.41
0016      DP=DP*RHO1/RHO
0017      DP=DP+DPC
0018      F9=(X3-X4)-DP
0019      JJJ=MOD(M1,100)
0020      IF(JJJ.NE.0) GO TO 1000
0021      WRITE(13,1100) DP,F9
0022      1100 FORMAT( 2E13.4)
0023      1000 CONTINUE
0024      RETURN
0025      END

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13.27.04

TIME

DATE 01/05/78

F5

DOS FORTRAN IV 360N-FO-479 3-8

DOS	FORTRAN IV	360N-FO-479 3-8	FIC	DATE	01/09/78	TIME	13.27.18	PAGE	0001
0001	C	FUNCTION F10(X4,X11)					000576		
0002		NOZZLE PRESSURE DROP					000577		
0003		COMMON RHO,VISC,PI,PAMB,PCCL,P5					000578		
0004		COMMON/AAA/ M1					000579		
0005		DIMENSION ZOZZ(100)					000580		
		DATA ZOZZ / 1.,1.,18.,C.,0.,10.,20.,30.,40.,50.,60.,70.,					000581		
		C 80.,90.,100.,110.,120.,130.,140.,150.,160.,200.,0.,0.15,0.30,					000582		
		C 0.551,1.05,1.65,2.4,3.3,4.35,5.50,6.6,7.95,9.30,10.7,12.15,					000583		
		C 13.6,15.2,23.75 /					000584		
		RHOT=45.41					000585		
0006		W=X11					000586		
0007		W=W/1.02					000587		
0008		CALL ENGUNB(ZOZZ,1.,W,0.,DP,1E)					000588		
0009		DP=DP*RHOT/RHO					000589		
0010		F10=X4-P5*14.696/29.92-DP					000590		
0011		JJJ=MMD(M1,100)					000591		
0012		IF(JJJ.NE.0) GO TO 1000					000592		
0013		WRITE(3,1100) DP,FIC					000593		
0014		1100 FORMAT( 2E13.4)					000594		
0015		1000 CONTINUE					000595		
0016		RETURN					000596		
0017		END					000597		
0018									

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0001      FUNCTION F11(X6,X9)
0002      VAPOR RETURN LINE PRESSURE DRUP
0003      DIMENSION FRI1(217),FRI2( 56),FRI3(273)
0004      COMMON RHO,VISC,PI,PAMB,PCCL,P5
0005      COMMON/AA/ M1
0006      COMMON/ELEVN/XK0,D,XL,Z0,Z1,EPS
0007      EQUIVALENCE (FRI1(1),FRI1(1)),(FRI3(218),FRI2(1))
      DATA FRI1 / 1.,1.,17.,14.,1.E-06,1.E-05,5.E-05,1.E-04,2.E-04,
C4.E-04,6.E-04,8.E-04,1.E-03,2.E-03,4.E-03,6.E-03,8.E-03,1.E-02,
C1.5E-02,2.E-02,3.E-02,3.E+03,5.E+03,8.E+03,1.5E+04,3.E+04,6.E+04,
C1.E+05,2.E+05,4.E+05,8.E+05,2.E+06,4.E+06,8.E+06,1.E+07,.044,.037,
C.032,.0275,.023,.0158,.0178,.0155,.0136,.012,.0102,.0092,.0083,
C.0081,.044,.037,.032,.0275,.023,.0198,.0178,.0155,.0138,.0122,
C.0108,.0098,.0092,.0085,.044,.037,.032,.0275,.023,.0198,.018,.016,
C.0142,.013,.0118,.0112,.0109,.0108,.044,.037,.032,.0275,.023,
C.0202,.0184,.0164,.0145,.0137,.0128,.0122,.0120,.0120,.044,.037,
C.032,.0275,.024,.0208,.0190,.0170,.0158,.0149,.0141,.0139,.0138,
C.0138,.044,.037,.032,.0275,.0245,.0217,.020,.0182,.0172,.0167,
C.016,.016,.016,.016,.044,.037,.032,.0275,.025,.0222,.0208,.0192,
C.0183,.0180,.0175,.0175,.0175,.0175,.044,.0375,.033,.029,.0252,
C.023,.0215,.0202,.0195,.019,.0189,.0188,.0188,.044,.038,
C.034,.0295,.0258,.0235,.0222,.021,.0202,.02,.02,.02,.02,.045,
C.039,.0355,.031,.028,.026,.025,.0242,.024,.0237,.0237,.0237,
C.0237,.047,.0415,.038,.034,.0315,.03,.0295,.029,.029,.029,
C.029,.029,.029,.0485,.0435,.04,.0365,.0348,.0335,.033,.0325,.032,
C.032,.032,.032,.032,.032,.0495,.045,.042,.0395,.0375,.036,.0358,
C.0355,.0355,.0355,.0355,.0355,.0355 /
      DATA FRI2 / .052,.047,.044,.0415,.040,.039,.0382,.038,.038,.038,
C.038,.038,.038,.038,.055,.0515,.049,.0462,.045,.044,.044,.044,
C.044,.044,.044,.044,.044,.044,.044,.059,.055,.053,.051,.050,.049,.049,
C.049,.049,.049,.049,.049,.049,.049,.049,.065,.063,.061,.059,.058,.0575,
C.0575,.0575,.0575,.0575,.0575,.0575,.0575,.0575 /
      C FLOW IN PPH,DIA IN INCHES,ABS. VLS IN LBM/(FT*SEC),EPS IN INCHES
      M=X9
      A=PI*(D**2)/4.
      REY=(W*D/(A*VISC))*12./3600.)
      REY=ABS(REY)
      EOD=EPS/D
      CALL ENGUNB(FRIC,1.EOD,REY,FF,1E)
      IF(REY.LT.3000) FF=64./4REY+.001
      Q=0.5*W*ABS(W)*144./((3600.)*2/RHU/(A**2)/32.2
      XK=XK0+FF*XL/D
      DP=XK*Q
      DP=DP+ RHO*(Z0-Z1)/1728.
      F11=(X6-PAMB)-DP
      JJJ=MOD(M1,100)
      IF(JJJ.NE.0) GO TO 1000
      WRITE(3,1100) REY,FF,Q,DP,F11
      1100 FORMAT( 5E13.4)
      1000 CONTINUE
      1000 RETURN
      END

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